Series 1931 Number 19

UNITED STATES DEPARTMENT OF AGRICULTURE

Soil Survey

of

The Tucson Area, Arizona

By

F. O. YOUNGS, in Charge

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and E. N. POULSON

Bureau of Chemistry and Soils

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SOIL SURVEY OF THE TUCSON AREA, ARIZONA

By F. O. YOUNGS, in Charge, A. T. SWEET, A. T. STRAHORN, T. W. GLASSEY, and E. N. POULSON [1]

AREA SURVEYED

The Tucson area lies in southeastern Arizona (fig. 1). It extends from the northern boundary of Santa Cruz County, where it joins with the previous soil survey of the Nogales area (*6*),[2] northward entirely across the eastern part of Pima County to the Pinal County line. It includes an area of 432 square miles, or 276,480 acres.

The area is irregular in outline. The main part is elongated and comparatively narrow, trending from its southern boundary first northeast, then north, and in its northern half northwest, with two prominent eastward-extending arms. One of these arms extends eastward from Tucson for a distance of about 12 miles and includes the lower part of the valley of Rillito Creek; the other covers about 80 square miles east of Continental in the southern part of the area, and consists of the Santa Rita Experimental Range which was surveyed under the administration of the United States Forest Service. The survey of this part of the area was made in more detail and on a larger scale than the remainder, for the purpose of determining the relationship of soils to forage plants and range management. The map of this part of the area has been reduced in scale and is published herewith as a part of the Tucson area. Unlike the main part of the Tucson area, it includes little farming land and extends well up into the foothills and higher foot slopes of the Santa Rita Mountains. In reducing the scale (for economy in publication), certain details in mapping have been sacrificed, and minor discrepancies between the soil map and text of this report may occur.

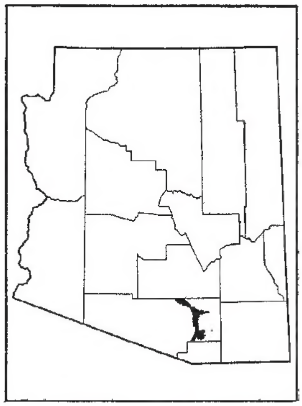

FIGURE 1.—Sketch map showing location of the Tucson area, Ariz.

The two parts of the survey are different in physiography, agricultural utilization, climate, vegetal environment, soils, and in the direct objective of the survey. The southeastern part covering the Santa Rita Experimental Range will (for clearness and simplicity) be referred to as the range part of the survey; the main part of the

[1] The authors express their appreciation for the cooperation of R. A. Greene, Department of Agricultural Chemistry, University of Arizona, in making determinations of total salt content, total nitrates, organic matter, and pH values of a number of soil samples from the Santa Rita Experimental Range; and of C. K. Cooperrider, M. J. Culley, P. B. Lister, and B. A. Hendricks, of the Southwestern Forest and Range Experiment Station; and of W. P. Taylor, Bureau of Biological Survey, for helpful information and suggestions.

[2] Italic numbers in parentheses refer to Literature Cited, p. 60.

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area, which includes the agricultural land and areas of settlement, which are confined mainly to the stream valleys, will be referred to as the valley part.

The country in which this area is situated consists of scattered rugged mountain ranges surrounded by larger areas of comparatively smooth desert plains. Most of the mountain ranges are low and narrow, but some of them extend considerable distances in a general southeast-northwest direction. They are very steep and rugged and are composed mainly of bare outcropping bedrock. Adjacent to the Tucson area on the east, however, are a number of higher ranges, including the Santa Catalina, Tanque Verde, Rincon, and Santa Rita Mountains, which attain heights of more than 9,000 feet. At the higher elevations, there is a thicker cover of soil and the land supports a fair growth of trees.

The area represents three general physiographic divisions: (1) The broad alluvial fans which emerge from mountain canyons and slope downward from the base of the mountain ranges, steeply near the mountains and farther away gradually flattening out upon the desert plains; (2) lower and flatter marginal areas of the fans which, with stream terraces, border the alluvial stream valleys and form narrow areas of mesa or bench lands; and (3) the comparatively narrow areas of alluvial bottom lands occupying the valleys of Santa Cruz River and other main drainage streams. In places the smooth and unbroken surfaces of the alluvial fans are interrupted or entrenched by intermittent streams which have cut deep narrow canyonlike valleys in the older fan materials at the places where they emerge from the canyon mouths, becoming shallow valley troughs or shifting unstable watercourses in the lower marginal fan areas bordered by low escarpments ranging in height from a few feet to more than 50 feet.

The valley part of the area includes the comparatively narrow alluvial valleys of Santa Cruz River and its main tributary, Rillito Creek, and of the lower courses of Pantano Wash, Canada del Oro, and Avra Wash, with bordering narrow strips and intervening or adjacent areas of the bench lands and alluvial fans. A few small areas of stony buttes and low mountains are also included.

The range part occupies a belt of land lying at the foot of Santa Rita Mountains. It includes small areas of the steep stony foothills, as well as a few isolated stony buttes, but the greater part of it consists of long, more or less gently sloping alluvial fans. The upper fans slope rather steeply and are deeply cut by drainage channels, canyons, or arroyos, but at a greater distance from the hills the slope gradually diminishes and the streams are less deeply entrenched, and in the lower part of the range the surface is comparatively smooth and gently sloping and the drainage channels shallow, in many places spreading out on the surface and becoming lost. In this lower part of the range area the slope is broken in places by steplike drops, breaks, or low escarpments, where erosion has cut the surface to lower levels, and numerous drainage channels or gullies occur along such breaks. In the vicinity of Continental, the drainage is deeply entrenched, leaving ridges between the channels, many of which are smooth or nearly flat topped.

Neither Santa Cruz River nor any of its tributaries within the area have a permanent flow of water along their entire courses,

although in a few places, where underground dikes of rock dam the underflow of Santa Cruz River, the stream is brought to the surface and flows a short distance before sinking again into the sandy bed. Though dry for long periods, the beds of these streams become raging torrents after heavy rains or the melting of snow in the mountains, and floods occasionally spread out over the bottom lands. The streams are cutting their channels deeper.

The area is, as a whole, exceptionally well drained. Small bodies of the flatter valley lands along Santa Cruz River show evidence, by the presence of "alkali" or salt accumulations, of having been poorly drained at one time, and along the upper course of Rillito Creek above the mouth of Sabino Creek are small areas having a high water table and slight surface accumulation of salts. In a few places near the mountains a small amount of seepage occurs along the bases of the alluvial fans.

The elevation of the valley land ranges from about 3,000 feet at the Pima-Santa Cruz County line on the south to somewhat less than 2,000 feet at the point where Santa Cruz River leaves Pima County at the Pinal County line. At the University of Arizona in Tucson, the elevation is 2,423 feet above sea level. The few low mountains or hills rise but a few hundred feet above the valley floor.

The elevation of the range part of the area surveyed ranges from 2,900 feet in the northwestern corner of the range to about 5,200 feet in the hills in the southeastern part. Mount Wrightson (locally called "Old Baldy"), among other peaks which rise abruptly to the southeast, attains an elevation of 9,432 feet.

This section of the country has a varied and interesting native vegetation. In the valley part creosotebush (*Covillea tridentata*) is the most common and wide-spread of the shrubby plants. In places bur-sage (*Franseria dumosa*) is abundant, and burroweed (*Isocoma coronopifolia*), desert sage (*Atriplex polycarpa*), and other species of *Atriplex* are of rather wide-spread occurrence. Many small trees grow in the drier parts of the area, including honey mesquite (*Prosopis glandulosa*), little leaf paloverde (*Cercidium microphyllum*), and ironwood (*Olneya tesota*), also numerous forms of cacti, including the giant cactus or sahuaro (*Carnegiea gigantea*), cholla, barrel cactus, and pricklypear, and ocotillo (*Fouquieria splendens*) is common. In the lower lands where moisture is more abundant, mesquite forms dense thickets in many places, and some hackberry grows. Along the stream channels, where water runs for a few months each year, cottonwoods and willows grow, also a few ash, walnut, and sycamore trees. After the winter and summer rainy seasons many small annual herbs spring up, among which are Indianwheat (*Plantago erecta*), alfileria or filaree (*Erodium cicutarium*), and a number of small fine-leafed grasses, both annual and perennial. On some of the lower lands, where "alkali" salts are present in rather large quantities, seepweed (*Dondia* sp.) is the commonest type of vegetation.

The range part of the area supports distinctly different types of vegetation throughout, desert shrubs dominating in the lower country and grasses in the higher, although a few plants grow throughout this area, the most common of which is velvet mesquite (*Prosopis velutina*). Burroweed (*Isocoma coronopifolia* or *Aplopappus fruiticosus*) is very common in the lower parts but diminishes in density

and vigor in the higher localities. Cholla and pricklypear (*Opuntia* sp.), barrel cactus (*Ferocactus wislizeni*), and paloverde (*Cercidium microphyllum* and *Parkinsonia torreyana*) grow over a rather wide range but are more common in the lower areas. Ocotillo and yucca (*Yucca elata*) are distributed over a wide vertical range, ocotillo on rather shallow gravelly soils, and yucca generally on rather loose sandy or gravelly soils. Creosotebush grows in the lower drier parts of the range but only on rather highly calcareous soils.

Grasses grow throughout the area but are sparse in the lower parts and much more plentiful and varied in the higher parts. Annual grasses predominate in the lower country and perennials at the higher elevations.

The Forest Service has classified the Santa Rita Experimental Range, on the basis of its grazing value, into three range-forage types of land which occupy belts or zones running parallel to the mountains, as follows: (1) The semidesert type, (2) the mesa type, and (3) the foothill type. Following is a brief description of each of these types, as given in the report.[3]

The semidesert type includes about 53 percent of the total area of the experimental range, situated largely on the lower, smoother, gently sloping fans. It is characterized by the dominance of browse species of plants, including mesquite (*Prosopis velutina*), catclaw (*Acacia gregii*), hackberry (*Celtis* sp.), wheelscale, locally known as shadscale (*Atriplex elegans*), and other minor species. Burroweed is one of the most prominent plants, and in a few small areas of calcareous soil creosotebush forms a nearly pure stand. On the gravelly ridges in the southwestern corner of the experimental range the vegetation is largely confined to cholla, ocotillo, and paloverde, with a small amount of mesquite and burroweed. There is a limited growth of perennial grasses, including Porter muhlenbergia (*Muhlenbergia porterii*), Rothrock grama (*Bouteloua rothrockii*), green sprangletop (*Leptochloa dubia*), the locally known wild millet (*Chaetochloa grisbachii*), *Aristida californica*, *A. arizonica*, and cotton grass (*Valota saccharata*). Slim triodia, locally known as low tridens (*Triodia mutica*), is very common on the more calcareous soils in this type of land. Numerous annual grasses, including various species of *Bouteloua* and *Aristida*, Indianwheat (*Plantago purshii*), and various annual weeds grow in this zone in years when spring and summer rains are plentiful.

The mesa type of land, comprising about 31 percent of the experimental range, lies at an elevation ranging from about 3,400 to 4,000 feet. It has a moderately sloping, comparatively smooth surface, though it is fairly deeply cut in places by drainage channels. It is essentially a grass area, though it has more browse than the foothill regions. The predominating grass on this type of land is Rothrock grama with black grama (*Bouteloua eriopoda*), the slender gramas (*B. filiformis* and *B. bromoides*), side-oats grama (*B. curtipendula*), hairy grama (*B. hirsuta*), several species of *Aristida* (*A. divaricata*, *A. californica*), and tanglehead (*Heteropogon contortus*) scattered over the area and locally important. Burroweed is a very prominent bushylike shrub found throughout the type, but it has no forage value. Browse species include velvet mesquite (*Prosopis velutina*),

[3] CULLEY, M. J. Unpublished report on grazing conditions on Santa Rita Range Reserve. 1927.

catclaw (*Acacia gregii*), *Calliandra* (*C. eriophylla*), chiefly, with other minor browse species locally in evidence.

The foothill type of vegetation covers about 16 percent of the area of the experimental range, the greater part of it growing at elevations ranging from 4,000 to 5,200 feet, although on the fan below Madera Canyon it descends to an elevation of about 3,400 feet. The upper part of the land is characterized by steep rocky hills, steeply sloping stony fans, deeply cut arroyos, and canyons, whereas the lower reaches are smoother and gently sloping, although also deeply cut in places by steep-sided drainage channels. The steeper lands offer more or less difficulty to grazing by livestock and, consequently, some protection for the grasses.

This is essentially a grass range supporting a good stand of slender gramas, curly-mesquite (*Hilaria belangeri*), hairy grama, side-oats grama, some black grama, silver beardgrass, locally known as "feathergrass" (*Andropogon saccharoides*), tanglehead (*Heteropogon contortus*), and various species of *Aristida* (*A. divaricata*, *A. californica*).

Burroweed is plentiful in places but much less prominent than on the semidesert and mesa types of land. Browse species include mesquite, hackberry, *Calliandra*, and, at the upper edge, evergreen oak, locally known as "live oak" (*Quercus* sp.).

The population of Pima County was 55,676 in 1930, the greater part of which was concentrated in the area surveyed. The rest of the county is largely a very thinly populated desert and mountainous country. The suburban district immediately surrounding Tucson is subdivided into small holdings and is rather thickly settled, but outlying rural districts have only a sparse populaton. The best developed and most thickly settled rural district, other than that near Tucson, is around Marana and Rillito. According to the 1930 census, 55.1 percent of the total population is native-born white, 3.7 percent foreign-born white, 28.9 percent Mexican, and 9.5 percent Indian. There are a few Negroes, Japanese, and Chinese.

Tucson, the only city in the area, had a population of 32,506 in 1930. This is an important health and winter-tourist resort, a railroad division and junction point, the seat of the University of Arizona, and an important trading and supply base for the surrounding mining, livestock-raising, and agricultural territory. A few small rural community centers include Marana, Rillito, Cortaro, Sahuarita, and Continental.

The area is served by the main line of the Southern Pacific Railroad and a branch line which runs to Nogales, connecting there with the Southern Pacific of Mexico.

Tucson is on United States Highway No. 80 which, within the area, is a paved or hard-surfaced road. United States Highway No. 89 is similarly surfaced, as are a number of the important roads. Some roads are graded, many of them graveled, and access is easy to most places within the area, although floods sometimes hinder travel by preventing the crossing of streams at certain points.

Electric lights and telephones are available in the city, over a large part of the suburban sections, and in the better developed farming communities.

The local market takes practically all the limited agricultural output of this area, although some of the cattle fed on the ranches are

shipped to Pacific coast and eastern markets. Much produce is shipped in for local consumption.

CLIMATE

The climate of Tucson and its environs, in common with that of the rest of southern Arizona lying at the lower elevations, is characterized by low annual rainfall, a dry atmosphere, rapid evaporation, high maximum and mean temperatures with long hot summers, short mild winters, and a great number of sunshiny days each year.

The mean daily range in temperature is very great as compared with that in most sections of the United States. The summer temperatures at Tucson are somewhat lower than they are at Yuma, Phoenix, and other lower lying points. This, together with the low humidity, has made Tucson a noted health resort for persons suffering with tuberculosis, asthma, and other pulmonary disorders, sinus trouble, rheumatism, arthritis, and other complaints. The mean relative humidity over a period of years has been 41 percent at the University of Arizona. The highest temperature recorded at the University of Arizona station at Tucson is 112° F., and the lowest is 6°. The mean annual temperature is 67.3°. The average length of the frost-free season is 249 days.

The mean annual rainfall at Tucson is 11.55 inches, with a range from 5.07 inches in 1924 to 24.17 inches in 1905. Snow very seldom falls, and when it does it lies but a short time on the ground.

Table 1, compiled from records of the United States Weather Bureau station at the University of Arizona, sets forth the more important climatic data for this area.

TABLE 1.—*Normal monthly, seasonal, and annual temperature and precipitation at University of Arizona, Pima County, Ariz.*

[Elevation 2,423 feet]

Month	Temperature			Precipitation		
	Mean	Absolute maximum	Absolute minimum	Mean	Total amount for the driest year (1924)	Total amount for the wettest year (1905)
	° F.	° F.	° F.	Inches	Inches	Inches
December	50.3	90	10	1.12	0.65	0.90
January	49.2	90	6	.77	.00	2.25
February	52.8	91	11	.90	(1)	4.15
Winter	50.8	91	6	2.79	.65	7.30
March	58.3	95	22	.75	1.65	3.88
April	64.3	100	25	.35	.41	3.53
May	72.4	111	32	.16	(1)	.02
Spring	65.0	111	22	1.26	2.06	7.43
June	82.3	112	37	.25	.17	.24
July	86.7	111	49	2.43	1.15	1.10
August	84.7	110	55	2.32	.08	.56
Summer	84.6	112	37	5.00	1.40	1.90
September	80.0	107	43	1.18	.19	2.84
October	69.0	101	27	.54	.16	.09
November	57.6	93	19	.78	.61	4.61
Fall	68.9	107	19	2.50	.96	7.54
Year	67.3	112	6	11.55	5.07	24.17

[1] Trace.

The rainfall takes place during two distinct periods. The heaviest rains are in summer (July to September) and lighter ones occur from December to March. The spring and fall months are generally very dry and sunshiny. The rainfall is insufficient to allow the growing of crops without irrigation, although it is of some benefit as a supplement to irrigation, especially as it cools the atmosphere and increases the humidity for a time, thereby producing a more favorable condition for the growth of plants. It is sufficient for the production of a luxuriant desert vegetation, and the flora of this district has an unusual variety, beauty, and charm. This undoubtedly explains much of the attraction of this section for winter tourists, which is a distinct asset.

The growing season, although long, is somewhat shorter than that in the Salt River Valley, Yuma Valley, Imperial Valley, and other lower lying districts of the Southwest, and the winters are somewhat colder. This comparatively slight difference in climate is reflected in a distinct difference in the adaptation of certain crops in this and the other districts named. Cotton, grain sorghums, alfalfa, and small grains (grown in winter) are well adapted here as in the other districts, but some of the more tender crops, or those requiring a long growing season and mild winters, do not thrive so well. Long-staple, or Egyptian, cotton, although it may be grown, does not, on account of the shorter growing season, yield so well as it does in the Salt River Valley. It yields better in the lower end of the area around Marana than in the upper end near Continental. The production of citrus fruits, which is a well-established industry in the other districts named, is largely untried here, although young plantings on the high alluvial-fan slopes near the base of Catalina Mountains are as yet (1931) unharmed by low winter temperatures. Plantings of citrus fruits in the lower valley lands subject to more severe frosts would unquestionably be attended by failure. Peaches, apricots, and other stone fruits, which are grown to some extent, are also subject to rather frequent damage by late spring frosts. Winter lettuce, peas, and other semihardy vegetables, which are also extensively grown at the lower altitudes, are frequently damaged by frost in this locality. This drawback, in addition to the fact that these vegetables come into competition with vegetables produced in other late-producing districts, has militated against a large development of truck growing in this area.

The Santa Rita Experimental Range lies at a higher elevation than the valley lands and in closer proximity to high mountains, and the climate is considerably modified, both as regards temperature and degree of aridity. In ascending from the lower part of the experimental range on the northwest toward the mountains on the southeast one gradually passes to a cooler and more humid section.

At the Florida station, at an elevation of about 5,000 feet and just south of the experimental range, rainfall records have been kept since 1901, and during that time the average annual rainfall has been 19.74 inches. The lowest amount falling in one year was 12.51 inches in 1903, and the highest, 38.21 inches in 1931. This station lies above the experimental range in the foothills, and the figures are somewhat higher than those obtained at other stations inside the range boundaries. The stations within the range have

been in operation since 1922. They show wide variations in total rainfall between the lower and higher elevations. The lowest average is that for Northwest station, at an elevation of about 2,900 feet (9.48 inches), and the highest is that for Parker station, at an elevation of about 4,250 feet (18.92 inches). For the foothill belt the average annual rainfall is 17.97 inches; for the mesa belt, 14.29 inches, and for the semidesert belt, 11.51 inches. The seasonal and monthly rainfall differs widely from year to year. For example, at Ruelas station in the foothills, 14.73 inches of rain fell in August 1931, and in August 1930 the rainfall was 2.90 inches.

Temperatures are lower in the experimental range than in the lower country. The lower temperature doubtless results in causing a given amount of rainfall to be more effective, as evaporation and transpiration are less. The difference in rainfall and, perhaps, to a somewhat less degree, the difference in temperature are reflected in the density and character of the vegetation and the character of the soils. In the higher country, grasses replace the characteristic desert-shrub vegetation growing at lower elevations, and the soil becomes darker and richer in organic matter.

AGRICULTURE

Scattered throughout the Tucson area are traces of prehistoric settlements, and it is thought by archeologists that the Indians in this district practiced agriculture on a limited scale in past centuries, with the aid of the scanty rainfall supplemented by the use of the occasional summer floods for irrigation. Even today such summer farms or gardens are cultivated in the adjacent "Papago Country" (*3*), where the Indians grow corn, beans, melons, pumpkins, squashes, and sorghums, drought-resistant strains of which they have developed.

The Mission of San Xavier del Bac, founded by Father Kino in 1700 (*3*), was established on an old Indian rancheria, where water was and still is diverted from Santa Cruz River for the irrigation of a small acreage. Another old rancheria, also watered by the river flow which comes to the surface here, was situated in the bottom lands along Santa Cruz River near the present site of the city of Tucson.

The present development of agriculture has taken place, however, largely since 1900. The Cortaro farms project in the lower part of the valley, the most important single irrigation project, was first irrigated in 1915. Expansion was rapid for a time, but the present trend in agricultural acreage is downward.

The 1930 Federal census figures for the crops grown in Pima County, which may be applied to this area, as practically all the production of crops is centered here, show a decrease in cultivated acreage from that given in previous census reports. Although the total acreage in farms was greater in 1930 than in 1920 or 1925, the cultivated acreage was considerably greater in 1925 than in 1930. In 1925 agricultural development was near its peak, but, owing to the shortage and high cost of water for irrigation and the low price of farm products, the acreage has been reduced. The census figures show a total acreage of crop land of 33,978 acres in 1929 as compared with 39,582 acres in 1924, a decrease of approximately 14 per-

cent. Observations in the field show that the decrease from 1930 to 1931 was very marked. Many fields, especially those in cotton in 1930, were lying idle in 1931. On the Cortaro farms project, which includes a total area of 70,000 acres, 12,000 acres have been under cultivation, but in 1931 only 6,000 acres were planted to crops.

Table 2 shows the acreage devoted to the principal crops in Pima County in 1919, 1924, and 1929.

TABLE 2.—*Acreage of the principal crops in Pima County, Ariz., in stated years*

Crop	1919	1924	1929	Crop	1919	1924	1929
	Acres	*Acres*	*Acres*		*Acres*	*Acres*	*Acres*
Corn	1,047	2,313	1,369	Cotton	804	7,089	7,954
Wheat	612	12,405	120	Potatoes	29	94	65
Barley	89	45	91	Beans (navy, pinto, and other)	4,208	237	705
Hay, all kinds	10,113	6,424	4,626	Sorghum for grain	301	404	354
Tame grasses	2,314	3,047	3,080	Sorghum for forage	1,341	207	1,871
Alfalfa [1]	[1] 1,790	[1] 1,845	[1] 1,888				
Wild grasses	23	185	294				
Small grains	5,025	3,192	1,252				

[1] Included in tame grasses.

The census reports 1,053 apricot trees of bearing age in 1929, 113 fig trees, 4,584 peach trees, 1,588 plum and prune trees, and 15,563 grapevines.

Table 3 gives the number and value of domestic animals, poultry, and bees in Pima County on April 1, 1930, as reported by the Federal census.

TABLE 3.—*Number and value of domestic animals, poultry, and bees in Pima County, Ariz., in 1930*

Livestock	Number	Value	Livestock	Number	Value
Horses	7,309	$293,750	Goats	2,638	$9,715
Mules	1,366	74,915	Chickens	68,069	55,817
Asses and burros	66	660	Turkeys	3,040	10,336
Cattle	89,821	4,511,499	Ducks	565	537
Swine	1,840	22,528	Bees (hives)	1,296	9,396
Sheep	7,344	53,667			

Table 4 gives the value of all agricultural products, by classes, in Pima County, in 1929, as reported by the 1930 Federal census.

TABLE 4.—*Value of agricultural products, by classes, in Pima County, Ariz., in 1929*

Crop	Value	Livestock and products	Value
Cereals	$15,650	Domestic animals, chickens, and bees	$5,031,947
Other grains and seeds	9,032	Butter, cream, and whole milk sold	351,098
Hay and forage	278,030	Butter churned	5,640
Vegetables, including potatoes and sweetpotatoes	77,985	Wool	13,986
Fruits and nuts	21,448	Mohair	4,141
All other field crops (principally cotton)	493,600	Poultry	119,291
Vegetables for home use	6,267	Chicken eggs	239,604
Forest products	56,215	Honey	1,873
		Total	5,767,580
Total	958,227	Total agricultural products	6,725,807

The number of cattle, milk cows, and chickens has increased greatly since 1920, and the number of mules has increased, but the number of horses and hogs has decreased.

It seems probable that the future will bring continued shrinkage of the area under cultivation, owing principally to the limited water supply which is being appropriated in ever-increasing quantities by the city of Tucson and its thickly settled suburban environs.

The soils of this area are, for the most part, poor in content of organic matter, humus, and nitrogen and comparatively rich in phosphorus, potash, lime, and other mineral elements. Organic compounds break down rapidly and, although the nitrates become quickly available to plants, they are rapidly removed from the soil. It is obvious, therefore, that one of the essentials in maintaining the productivity of these soils is to supply them with organic and nitrogenous matter. This is most easily accomplished by growing alfalfa, sweetclover, or some other legume in rotation with the other crops. The conservation and application of barnyard manure is also important in the maintenance of the supply of organic matter, and the growing and plowing under of green-manure crops may sometimes be advisable. The Pima soils are comparatively rich in organic matter, but even they will, without doubt, be benefited by the practices recommended.

Soil analyses show a content of phosphorus, generally considered abundant for vigorous plant growth, in the soils of this area, but field observations and plot tests in various parts of the Southwest and laboratory investigations at the University of Arizona (*1*) have shown that calcareous or alkaline soils in semiarid sections do not respond to applications of insoluble phosphates, although they do respond to the soluble acid phosphates. Presumably the phosphorus originally in the soil is largely in insoluble form and does not become readily available to plants. Very marked benefit has been derived from the application of superphosphate to many different crops, and its use is considered profitable on lettuce (*5*) and other crops of high acre value.

Breazeale [4] states that unavailablity of phosphorus accompanies a puddled condition of the soil and lack of penetration of air and water, and that the same results, obtained by adding acid phosphates, can be obtained by getting the soil in good tilth and good physical condition for the penetration of air and water. Such a condition is obtained by deep plowing, incorporation of organic matter, and careful, effective irrigation.

Dairying, cattle feeding, and poultry raising are important pursuits in this area, and small numbers of hogs and sheep are raised. Practically all the hay, grain, and fodder produced on the farms is fed locally, and many cattle are pastured on the ranches, especially in the winter. The local market absorbs the supply of milk produced; also a large part of the eggs, dressed poultry, hogs, and sheep; and some of the beef cattle.

Most of the beef cattle fed in the Tucson area are range cattle which are brought to the farms when grazing is scarce on the range.

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[4] F. J. Breazeale, of the Arizona Agricultural Experiment Station, at Tucson, is continuing experiments on the availability of phosphorus.

They are pastured on barley, oats, alfalfa, sweetclover, cotton stubble, and Johnson grass in the winter and spring, and many are fattened for market on the ranches. They are often given a supplementary feed of alfalfa or grain hay, together with hegari, corn, or barley for grain, and also corn silage.

SOILS AND CROPS[5]

The agricultural development of this area, which is confined to the valley part of the survey, is limited primarily by the water supply. In some places the character of the soil has determined the use of the land for agricultural purposes, but as a rule the availability of water for irrigation at a depth where it may be pumped economically is the most important consideration in determining areas for agricultural development.

The best soils are in the stream valleys or bottom lands along Santa Cruz River and Rillito Creek, where water is available at the least depth. The amount of good land greatly exceeds the potential water supply, and the best soils should be irrigated with the water supply available, although this has not been done in all places. In some small areas the local comparative freedom from frost is considered the most important factor in determining the adaptability of the land to plantings of citrus fruits.

The soils of this part of the area, like those of other parts of the arid Southwest, have certain dominant characteristics due to the environment under which they have been formed. The dry hot climate has produced soils containing a comparatively small, but readily available, quantity of organic matter (humus and nitrogen), and a high content of the more soluble mineral compounds, including lime and magnesium carbonates and salts of sodium and potassium, commonly called "alkali." In places the "alkali" salts occur in such excessive quantities as to be injurious to vegetation or to totally prevent its growth. Phosphates, although not present in very large amounts, are of sufficient quantity for normal plant growth, except where rendered unavailable by an excessively calcareous, alkaline, or puddled condition of the soil (*1*).[6]

The soils normally have a red or pink tinge, owing to the high degree of oxidation of the iron compounds they contain. In the case of those soils that have lain long enough for some soil development to

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[5] The Tucson area adjoins the Nogales area on the south, and a few discrepancies in the mapping of the soils along the border line are apparent. These are owing to the inclusion of very small bodies of soils with larger areas. For instance, the soil mapped as Gila fine sandy loam in the Tucson area is combined with Pima fine sandy loam in the Nogales area; Tubac gravelly clay loam of the Tucson area is combined with Tubac gravelly sandy loam in the Nogales area; a small area of Comoro gravelly sand in the Tucson area adjoins an area of Tumacacori gravelly loamy sand, dark-colored phase, in the Nogales area, with which this soil is included; and a very narrow area of Cajon sand in the Tucson area adjoins an area of Gila sand in the Nogales area, which includes small areas of the Cajon soil.

[6] Further information on phosphates and potassium in these soils may be obtained by consulting the following Technical Bulletins of the Arizona Agricultural Experiment Station; 35, Phosphate Solubility Studies on Some Unproductive Calcareous Soils; 36, The Relation of Phosphate Availability, Soil Permeability, and Carbon Dioxide to the Fertility of Calcareous Soils; 38, Electrodialysis as a Measure of Phosphate Availability in Soils and the Relation of Soil Reaction and Ionization of Phosphates to Phosphate Assimilation; 40, Studies on Iron, Aluminum, and Organic Phosphates and Phosphate Fixation in Calcareous Soils; 41, Nutritional Disorders in Alkaline Soils as Caused by a Deficiency of Carbon Dioxide; 42, The Physico-Chemical Relationships of Soil Phosphates; and 50, Potassium in Calcareous Soils.

have taken place, the surface soils have been slightly leached, and lime carbonate, together with other soluble compounds, has been carried into and accumulated in the subsoil, in places forming a more or less compact or cemented layer, locally referred to as caliche, a term used to signify lime hardpan. In parts of the area, notably at the higher elevations, the older soils have a heavy tough red subsurface or upper subsoil layer, which is caused by the transfer of clay and colloidal material from the surface soil and its accumulation in a lower layer.

The soils of the valley represent two broad groups: (1) The older upland soils which have a very definite accumulation of lime or caliche in the subsoil, and (2) those on the more recently deposited stream-bottom lands or lower alluvial fans, most of which are mellow and friable throughout and lack a very definite horizon of lime accumulation.

As has been suggested, the soils of the bottom lands developed from alluvium are those most used for agriculture and the best adapted to such use. These soils are included in the Gila and Pima series (pl. 1, *A*).

The younger soils on the alluvial fans, included in the Cajon, Anthony, and Comoro series, might be farmed if abundant water for irrigation were available at a reasonable expense. Small areas of the soils of the uplands, terraces, and alluvial fans, included in the Tucson, Mohave, and Laveen series, with soft caliche, are under cultivation, but the soils of the Pinal series, having true hardpan or firmly cemented caliche are of very little value. The city of Tucson is built on a large body of the poor shallow Pinal sandy loam, where deep holes must be dug or blasted for trees and shrubs, and earth must be hauled in for the establishment of lawns and gardens.

The foregoing general description of the soils must be modified to apply to the soils of the Santa Rita Experimental Range. It holds fairly well in the lower drier areas, but in the higher parts, with their greater rainfall, much leaching has taken place, thereby removing the more soluble salts to considerable depths. The surface soils and upper subsoil layers are in most places neutral or slightly acid, but only in a few places, except in very loose soils, has the lime carbonate been removed to a depth of more than 6 feet, and the lower part of the soil everywhere shows an alkaline reaction. These higher lying soils are much darker and have a higher content of organic matter than those in the lower country, owing to the heavier grass cover.

The soils of the range part of the survey represent three broad groups: (1) The brown deep friable sandy soils which are developed from comparatively recent deposits of alluvium, (2) the old red and brown soils with tough red subsoils, and (3) the old gray limy soils with more or less firmly cemented subsoils. The first group includes the Comoro soils with brown or dark-brown surface soils, the Tumacacori soils with dark-brown or dark dull-brown surface soils, and the Cajon soils which are light brown. In the second group are the Tubac soils which are dull red or pronounced reddish brown and have limy, more or less cemented, subsoils at a depth ranging from

2 to 3 feet below the surface; the White House soils which are dark reddish brown or dark brown and leached of lime carbonate to a depth ranging from 4 to 6 feet; and the Continental soils which are intermediate in character, of lighter reddish brown or dull-red color, with accumulated lime carbonate at a depth of 2 or 3 feet, but lacking the cementation of the Tubac soils. The Coronado soils, which are shallow soils developed on stony buttes and foothills, and the Sonoita and Mohave soils, which are somewhat similar to the Continental and Tubac soils but are less highly developed and not so tough in the subsoil, should probably be considered as belonging to this group. The third group—the gray soils—includes the Pinal soils, which have a firmly cemented lime hardpan or caliche layer, and the Laveen soils which have softly cemented subsoils. The Tucson and Anthony soils are intermediate between the first and third groups.

In determining the distribution and growth of the different plant species on the Santa Rita Experimental Range, it seems that the character of the soil has played an important role but is perhaps secondary to the moisture supply, that is, the amount of moisture available to the plants. This moisture supply is, however, not only dependent on rainfall, but also on the quantity of the rainfall absorbed by the soil and given up by the soil to the plants. Thus the soil has a very important indirect influence. Other important factors are temperature, humidity, grazing by livestock, rodents, competition between plants, and seeding habits of plants. In specific instances it may be demonstrated that the differences in vegetation are not due to soil differences, although they may, in the course of time, induce changes in soil character.

Apparently the physical characteristics of the soil are, as a rule, more important than its chemical composition in determining its adaptabiltiy to the growth of grass, although chemical differences seem to have a distinct correlation with the distribution of certain species of grasses and shrubs, and also influence their height and vigor of growth. Local soil differences apparently have much less effect in the more moist cooler upper belt than in the lower drier and hotter parts of the experimental range. In the lower and central parts, in order to support a good growth of grass the surface soil must be rather coarse, loose, and of fair depth. The best growth is made on smooth gently sloping areas of medium or coarse sandy loams of the brown group (Tumacacori and Comoro soils) which are many feet deep. Where the older redder and dark-brown soils (Tubac, Sonoita, White House, and Continental) have sufficient depth of sandy surface soil, they produce a good growth of grass, but in many places burroweed and mesquite predominate. On slopes which are covered with a loose mulchlike layer of gravel, grasses do fairly well in places, although the stand in general is not thick. On the old tough heavy-textured soils (Tubac, Continental, and White House), on small spots where rodents have loosened the soil, where loose sandy material has lodged about brush, or where litter and leaves have accumulated, grasses get a start, but most of the land is practically bare.

In many places, especially in the semidesert and mesa types of land, local differences in the vegetation occur where no apparent soil difference exists. Such differences would seem to be due to killing out of some grass species by overgrazing or trampling and subsequent invasion by other species of grass and brush.

The limy gray soils seem to favor the growth of creosotebush in the lower drier country, and this shrub forms nearly pure stands in many places on such soils, although it rarely grows on other soils. Such soils also support a growth of low tridens grass. At higher elevations the limy soils produce a fairly good growth of perennial grasses and a more varied shrub cover.

As previously stated, soil differences have a much less important effect on vegetation in the higher, more moist, part of the experimental range than in the lower country. Very thin soils, with only a few inches of soil over bedrock or a tough red subsoil, produce a good stand and vigorous growth of grasses, and in many places on such thin soils curly mesquite is the predominating grass.

In soil classification the soils are grouped, on the basis of similar characteristics, into series, types, and phases. The soil series is a group of soils which have certain physical and chemical characteristics in common, such as color, content of organic matter, lime carbonate, and other salts, physical structure, texture, arrangement of horizons or layers from the surface down, character of parent rock or soil material, mode of accumulation of soil material, and other natural features. The soil type is a division within a series based on the texture (size of soil particles) of the surface soil. The phase is a minor variation within a soil type, such as a soil with slightly different texture or color, or one which occupies steep or rough land. The series is given a geographic name by which it is known and recognized, the type name indicates the texture of the surface soil, and the phase name indicates some minor characteristic. For example, in the name White House coarse sandy loam, stony phase, White House indicates a series of soils characterized by dark reddish-brown surface soils over tough dark-red clay subsoils, which are leached of lime carbonate to a depth of more than 3 feet; the type name—coarse sandy loam—indicates the texture of the surface soil; and stony phase indicates that the soil contains more stone than typical White House coarse sandy loam.

In the following pages the soils of the Tucson area are described in detail, and their agricultural relationships are discussed; the accompanying soil map shows their location and distribution; and table 5 gives their acreage and proportionate extent.

TABLE 5.—*Acreage and proportionate extent of soils mapped in the Tucson area, Ariz.*

Type of soil	Acres	Per-cent
Gila loam	10, 880	3. 9
Gila loam, dark-colored phase	1, 024	. 4
Gila silt loam	10, 880	3. 9
Gila very fine sandy loam	4, 224	1. 5
Gila fine sandy loam	12, 096	4. 3
Gila sandy loam	2, 304	. 8
Gila silty clay loam	6, 784	2. 4
Gila clay loam	1, 920	. 7
Gila fine sand	4, 032	1. 5
Gila loamy fine sand	4, 032	1. 5
Pima silty clay loam	9, 664	3. 5
Pima clay	640	. 2
Comoro coarse sandy loam	10, 176	3. 7
Comoro sandy loam	4, 416	1. 6
Comoro sandy loam, gravelly subsoil phase	192	. 1
Comoro gravelly loamy sand	1, 536	. 5
Comoro loam	576	. 2
Comoro clay loam	384	. 1
Tumacacori coarse sandy loam	5, 312	1. 9
Tumacacori gravelly loam	320	. 1
Tumacacori gravelly loam, stony phase	128	. 1
Tumacacori gravelly loam, shallow phase	192	. 1
Cajon sand	11, 328	4. 1
Anthony sandy loam	14, 656	5. 3
Anthony sandy loam, calcareous phase	384	. 1
Anthony sandy loam, red phase	1, 280	. 5
Anthony gravelly sandy loam	320	. 1
Anthony loam	4, 800	1. 7
Anthony loam, calcareous phase	128	. 1
Anthony silty clay loam	2, 432	. 9
Sonoita sandy loam	4, 224	1. 5
Tucson loam	24, 704	8. 9
Tucson gravelly loam	128	. 1
Mohave loam	6, 400	2. 3
Mohave clay loam	5, 952	2. 2
Mohave clay loam, dark-colored phase	896	. 3
Mohave sandy loam	5, 760	2. 1
Mohave sandy loam, dark-colored phase	1, 088	. 4
Laveen gravelly sandy loam	832	0. 3
Laveen loam	10, 496	3.
Laveen sandy loam	7, 424	2. 7
Palos Verdes gravelly sandy loam	4, 864	1. 7
White House gravelly sandy loam	1, 088	. 4
White House gravelly sandy loam, stony phase	896	. 3
White House coarse sandy loam	4, 416	1. 6
White House coarse sandy loam, deep phase	640	. 2
White House coarse sandy loam, stony phase	1, 344	. 5
White House coarse sandy loam, steep stony phase	1, 792	. 6
White House gravelly loam	2, 176	. 8
White House gravelly loam, stony phase	128	. 1
Continental sandy loam	2, 432	. 9
Continental gravelly loam	1, 152	. 4
Continental gravelly loam, stony phase	512	. 5
Pinal gravelly sandy loam	6, 912	2. 2
Pinal gravelly sandy loam, steep phase	448	. 2
Pinal gravelly sandy loam, red phase	448	. 2
Pinal gravelly sandy loam, dark-colored phase	512	. 2
Pinal gravelly sandy loam, rock-outcrop phase	192	. 1
Pinal sandy loam	16, 640	6. 0
Pinal sandy loam, deep phase	1, 152	. 4
Tubac sandy loam	1, 984	. 7
Tubac clay loam	1, 984	. 7
Tubac gravelly clay loam	3, 776	1. 4
Tubac gravelly clay loam, stony phase	512	. 2
Coronado stony coarse sandy loam	1, 856	. 7
Coronado stony loam	128	. 1
Rough broken and stony land	16, 704	6. 0
River wash	6, 848	2. 5
Total	276, 480	------

SOILS OF THE GILA SERIES

The Gila soils, which range in texture from fine sand to silty clay loam, have light-brown, light grayish-brown, or pinkish-brown friable surface soils and stratified subsoils which are typically mellow, permeable, and favorable to good root development of plants. The difference in the texture of the soil material has a marked influence on the ability of the soil to retain moisture, and this feature, together with the greater inherent productivity of the finer textured materials, makes the medium and heavier textured soils more productive and better adapted to irrigation farming than the very light textured soils. "Alkali" accumulations occur in places in sufficient quantities to interfere with the production of crops.

The Gila soils are developed from recent stream deposits, and they occur only in the vicinities of the larger stream channels in the valley part of the area.

In a few places the subsoil materials include dark-colored bands or layers of interbedded materials of the associated darker colored Pima soils.

Gila loam.—Gila loam is widely distributed and is perhaps the most important agricultural soil in the area. It is largely developed in the Marana district on the Cortaro farms project. Perhaps 50 percent or more of this soil is, or recently has been, under cultivation.

The surface soil is light-brown or light grayish-brown friable fine-textured loam containing much fine sand. The subsoil consists of friable stratified materials, takes and holds moisture well, and is a very favorable medium for plant growth. Only small areas of this soil are seriously affected by an accumulation of "alkali," or salts.

Hegari (a grain sorghum), alfalfa, and cotton, in the order named, are the crops of greatest importance. They occupy about 35, 25, and 20 percent, respectively, of the cultivated land. Barley (for hay, pasture, and grain) also occupies a large acreage, probably 10 percent. Corn (for silage and grain), wheat, and potatoes are of minor importance, and peaches, apricots, grapes, figs, beans, cabbage, and other fruit and truck crops are grown to some extent.

Cotton was, until recently, the most important crop, but the acreage has been greatly reduced on account of low prices received, the high cost of irrigation water, and other high production costs. Cotton pests, including the leaf worm, pink bollworm, and bollweevil, have also had their share in making cotton growing unprofitable in this locality.

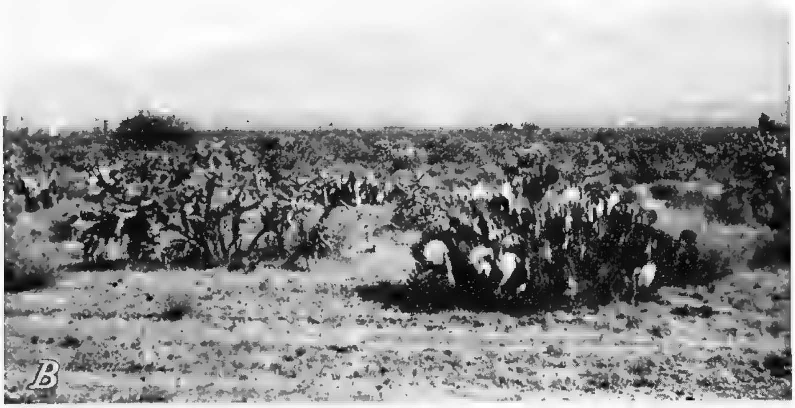
Much of the cotton acreage has been given over to the growth of hegari which produces good crops of grain and fodder with a minimum quantity of water in a short growing season. The same land is often used for a winter crop of barley which is pastured in winter and early spring and later cut for hay or harvested for grain. Acre yields of hegari on this soil range from 1 to 3 tons of grain, with an average of about 2 tons, and from 4 to 8 tons of fodder. This crop is used as feed for cattle and poultry. Alfalfa yields range from 4 to 10 tons, averaging about 6 tons, and many of the fields are pastured during the winter.

Short-staple cotton yields range from one-half to 2½ bales an acre, with an average of about 1 bale. Long-staple cotton (Pima) yields from one-half to 1½ bales, averaging about three-fourths of a bale. Barley hay yields about 2 tons, and barley grown for grain from 20 to 30 bushels. Potatoes yield from 40 to 150 bushels.

Gila loam, dark-colored phase.—The dark-colored phase of Gila loam occupies a small area along Rillito Creek above the mouth of Sabino Creek, and only a small part of this is under cultivation to small grains, pasture, and garden truck.

This soil is very similar to typical Gila loam, but it is darker. The surface soil is dark grayish brown or dark brown like that of the Pima soils. In places it contains a small quantity of "alkali." It is a good rich soil but, because of its small extent and the shortage of water, is not an important agricultural soil.

Gila silt loam and Gila very fine sandy loam.—Gila silt loam and Gila very fine sandy loam are soils which are very similar to Gila loam, but they differ from that soil in texture of the surface soil material. They are fine floury soils which hold moisture well and are very well adapted to growing all the common farm crops, although when irrigated they have a tendency to seal or "slick over" and absorb water rather slowly. In most places the subsoils are similar to



A, Hay-baling machine in alfalfa field on soils of the Gila series, near Continental. *B*, Native vegetation, mainly species of cacti, on Tucson loam.

the surface soils, but they are variously and irregularly stratified. Gila silt loam shows a tendency toward heavier textured darker colored layers, but in Gila very fine sandy loam areas occurring along Santa Cruz River around Continental the subsoil in some places is rather light and loose. Such areas have a lower water-holding capacity than the rest of the soil.

These two soils are rather widely distributed, occupying long narrow bodies paralleling Santa Cruz River and areas along Rillito Creek. Gila silt loam has a total area of 17 square miles, and Gila very fine sandy loam 6.6 square miles. Only a small proportion of these soils (about 30 percent of the silt loam and 20 percent of the very fine sandy loam) is under cultivation, not because of the character of the soils, but because water is not readily available, as most of the areas occur outside the irrigated districts.

As on Gila loam, the most important crops are grain sorghums, alfalfa, cotton, and barley (for pasture, hay, and grain), and yields are much the same as on that soil.

Gila fine sandy loam.—Gila fine sandy loam is very similar to Gila loam. The surface soil is somewhat lighter in texture than that of Gila loam, being fine sandy loam or medium sandy loam. The subsoil in most places, notably in the Marana district, consists of fine-textured stratified materials of good water-holding capacity, but in a few places, especially along Rillito Creek and along Santa Cruz River above Continental, the subsoil is coarser and looser than the surface soil and has a rather low moisture-holding capacity. Such areas require frequent irrigation for successful crop production.

This soil is rather widely distributed along the bottom lands of Santa Cruz River and Rillito Creek and has a total area of 18.9 square miles. Perhaps 35 percent of the land is under cultivation, and most of the rest would be cultivated if an adequate supply of water were available.

The important crops are alfalfa, cotton, and hegari. In the Marana district this soil is particularly prized by farmers for the production of alfalfa and cotton, which are said to produce somewhat higher yields than on the finer textured soils. This soil is very easy to plow and cultivate, takes water very readily, and warms up more quickly in the spring than do the heavier soils.

Small areas of this soil on the southern boundary of the Tucson area join with areas of Pima fine sandy loam of the Nogales area (*6*). In the Nogales area the soils of the alluvial stream bottoms are of somewhat higher organic-matter content and of darker color than in the less elevated and more arid Tucson area, with a gradual transition taking place near the boundary between the two areas. In the Nogales area the lighter colored transitional soil, recognized in the Tucson area as Gila soil, was included with Pima fine sandy loam owing to its small extent.

Gila sandy loam.—Gila sandy loam is not very extensive in the Tucson area. The surface soil is medium- or coarse-textured sandy loam which, other than in its coarser texture, is similar to Gila fine sandy loam. The subsoil consists of stratified friable materials ranging from coarse to fine, and the water-holding capacity is fair or rather poor. Only a small proportion of the land is under cultivation. Cotton and alfalfa are the principal crops. The soil is fairly

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well adapted to these crops, although its value is somewhat less than that of Gila fine sandy loam because of its somewhat greater water requirement.

Gila silty clay loam.—The surface soil of Gila silty clay loam is light-brown or brown silty clay loam of rather friable granular structure, but, because of its heavier texture, it is harder to plow and cultivate than are Gila loam or the other lighter textured Gila soils. The silty clay loam does not absorb water so readily as the other Gila soils, but it has a high water-holding capacity. In most places the subsoil is similar to the surface soil, although in some places it is stratified with lighter textured materials and banded with darker colored layers.

About 40 percent of this soil, which has a total extent of 10.6 square miles, is under cultivation. It is a fertile soil and produces good crops of cotton, alfalfa, hegari, and small grains (barley and wheat). It seems better adapted to grain growing than are the lighter textured soils, but probably it returns somewhat lower yields of alfalfa and cotton. In most places it is practically free from an accumulation of "alkali." Some bodies are subject to overflow, either from Santa Cruz River or from side washes, and crops on these areas have at times been damaged or destroyed.

Gila clay loam.—Gila clay loam is a soil of small total area, occurring most extensively northwest of Marana. Some small bodies lie around Sahuarita. About 60 percent of the land is cultivated.

This soil is very similar to Gila silty clay loam, but it contains a larger percentage of sand and is clay loam in texture. It produces the same crops—hegari, alfalfa, cotton, and barley—and has essentially the same value as Gila silty clay loam.

Gila fine sand.—Gila fine sand consists of light grayish-brown loose leachy fine sand or medium sand. It is rather widely distributed in long narrow bodies along or paralleling the channels of Santa Cruz River, Rillito Creek, and Pantano Wash. This soil is not under cultivation and has little or no agricultural value, on account of its looseness and the fact that it would require a large quantity of irrigation water. It has a hummocky or, in places, small dunelike surface relief and is easily shifted by the wind. Much of it is almost devoid of vegetation, but in places it supports some creosotebush, burroweed, and mesquite.

Gila loamy fine sand.—Gila loamy fine sand is similar to Gila fine sand, but it is somewhat loamier and firmer than that soil. It does not blow so readily and has a heavier vegetal cover, mostly creosotebush and burroweed. In places in the Marana district this soil has a finer textured subsoil, but in most places it is rather light and leachy.

Only a small proportion of this soil, northwest of Tucson on the university farm and east and north of that place, is cultivated and produces satisfactory yields of barley hay, cotton, peaches, and apricots. Its chief drawback is that it requires frequent irrigation, as the water-holding capacity is low. Potatoes seem fairly well adapted to this soil.

SOILS OF THE PIMA SERIES

The Pima soils, like the Gila, are developed from stream-laid materials of comparatively recent deposition. They are dark gray-

ish-brown soils of rather heavy texture but in most places are friable and granular. They contain a higher percentage of organic matter than the Gila soils and, where not affected by accumulations of salts, are as a rule productive. In places the subsoil is rather heavy in texture and somewhat compact and tough. Many areas have a high "alkali" content and are not suitable for growing crops without reclamation. These soils do not occur in the range part of the area surveyed.

Pima silty clay loam.—Pima silty clay loam is one of the more important agricultural soils in the Tuscon area. It includes an area of 15.1 square miles, of which approximately 50 percent is cultivated.

The surface soil is dull dark grayish-brown rather friable and granular silty clay loam containing a comparatively large quantity of organic matter. The subsoil is typically stratified and rather variable, although it is normally of medium or rather heavy texture. In many places it is lighter colored than the surface soil—light grayish brown—representing interbedded material of the Gila soils. In most places this soil absorbs and holds moisture well and is productive, but many areas, especially northwest of Tucson, are heavily impregnated with "alkali", or salts, and are therefore of little agricultural value. For successful reclamation, the most strongly affected spots would require washing or leaching, and with the limited water supply of this district this is impracticable.

The important crops are alfalfa, pasture grasses, barley, and oats (for pasture, hay, and grain), cotton, hegari (for grain and fodder), and corn (for silage and grain). Wheat is of little importance. Much of this land lies in large ranches on which cattle are pastured and fed. Much of it is infested with Johnson grass, and for this reason pasturing is the best use to which it can be put. The proportion of the land used for the different crops differs from year to year. The present tendency is for cotton, once an important crop, to become of minor importance, largely because of low prices and high cost of production. Some of the land has been practically abandoned and irrigation discontinued, but it still produces some Johnson grass which is used for pasture. Truck crops, including turnips, beets, carrots, peas, cabbage, lettuce, and peppers, are grown on small areas, and this soil is well suited to their growth; but the limited local market and colder winter climate, as compared with other winter truck-growing districts, prevent much expansion along this line.

Alfalfa is estimated by farmers to yield from 2 to 8 tons an acre on this soil, with an average of about 6 tons; barley or oat hay yields from 1½ to 3 tons; barley for grain, 15 to 20 bushels; cotton (short staple), ½ to 1 bale; corn for silage, 10 to 15 tons; and hegari, 1½ to 2½ tons of grain.

Pima clay.—Pima clay covers only a few small areas. It is heavy, tough, dark, or dull grayish-brown clay which is rather impervious and bakes easily. The areas northwest of Tucson contain a high percentage of salts. Little or none of this land is under cultivation, and it seems a less desirable agricultural soil than Pima silty clay loam. It would be harder to plow, cultivate, and irrigate, and under most conditions would be less productive. Where not too badly affected by "alkali" it would doubtless be fairly well adapted to small grains and pasture but less desirable for alfalfa and cotton.

SOILS OF THE COMORO SERIES

The Comoro soils comprise the most extensive group of soils in the experimental range. They occur throughout the lower semi-desert and central parts. They are inextensive in the valley part of the area. They include Comoro coarse sandy loam, which is by far the most extensive and important; Comoro gravelly loamy sand, Comoro sandy loam, with a gravelly subsoil phase, Comoro loam, and Comoro clay loam. These soils are brown, dark dull reddish brown, or dark brown, and they consist largely of rather coarse gritty material originating from granite, syenite, and similar igneous rocks. They consist of recent alluvial-fan deposits and have little or no soil development, except a moderate accumulation of organic matter in the topmost foot or two. Except for the darker color imparted by this organic matter, these soils are typically rather uniform from the surface down, are leached of lime, and show no compaction, no noticeable accumulation of lime carbonate or other salts in the subsoil, and little or no accumulation of clay and colloids. They occupy gently or steeply sloping alluvial fans. They are friable and, with the exception of the coarser textured soils, are of moderately good water-holding capacity.

Areas within the valley part of the area could be utilized for most of the crops commonly grown, if water for irrigation were available. The higher lying areas within the experimental range are important on account of the native grasses and other plants of value for grazing.

Some of the lower lying valley areas differ from the typical soils of this series in that they include a few areas with subsoils having an accumulation of lime.

Comoro coarse sandy loam.—This is the most extensive soil and one of the most important grass-producing soils in the experimental range. It does not occur in the valley part of the area. In many places it produces a thick stand of grasses. The annual grasses are the most abundant, but in places where grazing is not too heavy the land supports a good growth of perennial grasses, including *Aristida californica*, *A. arizonica*, *Bouteloua rothrockii*, *Muhlenbergia porterii*, *Valota saccharata*, and *Chaetochloa grisbachii*. Black grama grows in some places, and in a few places tanglehead. In places there is considerable burroweed and a scattered growth of mesquite, but these two plants are not nearly so plentiful as they are on some of the heavier and redder soils in the same localities.

The surface soil is brown or dark-brown mellow or loose medium sandy loam or coarse sandy loam, which extends to a depth ranging from 1½ to 2½ feet. In places it has a slight red tinge. The subsoil is light-brown or light reddish-brown loose coarse sandy loam. The soil material is derived from granite, syenite, and similar igneous rocks.

This soil and similar soils are especially favorable for the growth of grass, because the loose open character allows quick penetration of moisture, and even a very rapid rainfall is largely absorbed. This is especially important during the violent summer thunderstorms prevalent in this part of the country. Another important factor is the large proportion of the soil moisture which is available to plants, as this soil has a very low wilting coefficient. Fur-

thermore the soil is well aerated, plant roots penetrate it readily, and the surface does not bake and cause a hard physical condition unfavorable for the development of growing plants.

Comoro sandy loam.—Comoro sandy loam is very similar to Comoro coarse sandy loam, but the surface soil is finer in texture, averaging medium sandy loam rather than coarse sandy loam. However, the texture is extremely variable, ranging from loam to medium or coarse sandy loam, and in places the soil contains rather large quantities of gravel. The subsoil consists of grayish-brown or brown irregularly stratified fine and coarse materials which, in the lower lying valley areas of lower rainfall, locally contain a fairly large concentration of lime carbonate in the form of faint mottling or veining. The material shows little or no compaction, and the water-holding capacity under irrigation ranges from good to rather poor, depending on the difference in the texture of the soil material.

Comoro sandy loam is largely developed from materials coming from the finer grained igneous rocks, such as rhyolite and trachyte. It is much less extensive than Comoro coarse sandy loam.

In the range part of the area this is a good soil for grass, although it produces a rather large proportion of annuals and supports considerable burroweed and mesquite in places. In the valley this soil occupies the higher parts where the rainfall is greatest. It is most extensive south of Continental, bordering the Santa Cruz bottom lands on either side, and small areas lie along Rillito Creek at and above the mouth of Sabino Creek. The vegetation here consists of mesquite, burroweed, a good growth of small annual herbs, and a small quantity of fine-leaved grasses. It affords some grazing after the winter and summer rainy seasons. If this soil could be irrigated it would, no doubt, be productive and well adapted to most of the common crops of the area, although in some places it would require rather frequent irrigation.

Comoro sandy loam, gravelly-subsoil phase.—The gravelly-subsoil phase of Comoro sandy loam is similar to typical Comoro sandy loam, but it has a thin surface soil over a subsoil, or substratum, consisting of beds of porous gravel and cobbles. Gravelly or stony ridges or bars occur in places on the surface. This is a droughty soil with a low water-holding capacity. It occurs only in the range part of the area. Mesquite is common along the drainage channels, and burroweed is more or less abundant. The growth of grasses, many of which are annuals, is sparse.

Comoro gravelly loamy sand.—Comoro gravelly loamy sand occurs only in the valley. It is similar to Comoro sandy loam but contains a large quantity of gravel in the surface soil and subsoil. It is too coarse to be desirable for cultivation and would require excessive amounts of irrigation water. None of it is cultivated, and it is hardly probable that any of it ever will be. It supports a growth of mesquite, burroweed, cacti, small annual herbs, and fine-leaved grasses, and it has some value as grazing land.

A small area of Comoro gravelly loamy sand joins with an area of closely related dark-colored soil of the Nogales area, recognized in that area as Tumacacori gravelly loamy sand, dark-colored phase, with which the Comoro soil merges.

Comoro loam.—Comoro loam occurs only in the range part of the area, on the more level ground at the foot of the fans occupied by

Comoro coarse sandy loam. The surface soil is brown, reddish-brown, or rather dark brown somewhat gritty loam, in places containing a large quantity of silt. The subsoil in many places is considerably stratified with layers of material ranging from clay loam or silt loam to coarse sandy loam. In most places the finer materials are dark brown or dark reddish brown, and the coarser materials are somewhat lighter colored. Normally the material contains no lime carbonate within a depth of 3 feet below the surface, but locally it may be slightly calcareous.

This soil supports a scant growth of grasses—mostly annuals—and in places a few weeds. Burroweed and mesquite are common. Many areas are practically bare of vegetation. On account of its fine texture, this soil does not absorb moisture quickly, and much water is lost through run-off. The soil has a tendency to bake and has a much higher wilting coefficient than the sandier soils.

Comoro clay loam.—Comoro clay loam occupies a few small bodies in the northwestern corner of the experimental range. It occurs as rather flat low-lying strips at the foot of the fans composed of the coarser Comoro soils. It is of little grazing value, as its vegetal cover consists mainly of scattered mesquite and burroweed. There is little or no grass, and many bare spots are in evidence.

The surface soil is dark-brown clay loam or silty clay loam, which in most places is not calcareous, but in many places the subsoil is slightly calcareous, being faintly veined or netted with white lime carbonate. In many places the Comoro soil material overlies the old tough red material characteristic of the Continental and the Tubac soils, at a depth ranging from 2 to 6 feet. It is probable that the heavy texture of this soil, its slowness to absorb moisture, and the fact that it lies in a belt of low rainfall, are responsible for its poor vegetal growth.

SOILS OF THE TUMACACORI SERIES

The Tumacacori soils, which are extensive in the higher parts of the experimental range, are very similar to the Comoro soils, but, because they occur at higher elevations with greater rainfall and lower temperatures, they have supported a heavier growth of grasses and are much darker in color and richer in organic matter. The color of the surface soils ranges from dark brown to dark dull brown, although the immediate surface material is somewhat bleached, giving the soil a lighter grayish brown or reddish-brown appearance. The dark color extends to considerable depth, the topmost foot or two being the darkest, but even to a depth of 4 feet or deeper the dark-brown color persists, gradually changing to medium brown or slightly reddish brown.

Both surface soils and subsoils are of loose open character. The subsoils are irregularly stratified and of variable texture. They contain many gravelly layers or embedded gravel. These soils characteristically have a sharp gritty feel and are leached of lime, but they are without developed horizons having compaction, structural development, or accumulations of clay and colloidal materials.

The soils of this series occur only in the range part of the area.

Tumacacori coarse sandy loam.—Tumacacori coarse sandy loam is an important and extensive soil in the upper mesa and foothill belts of the experimental range. It is second in extent only to Comoro

coarse sandy loam and supports an even denser grass growth. Among the grasses common to this soil are Rothrock grama, black grama, slender gramas, tanglehead, a number of species of *Aristida*, and in places, an abundance of annual grasses.

The surface soil is dark-brown coarse sandy loam or fine gravelly loam. The surface layer, ranging from a few inches to a foot in thickness, is very dark, and the dark color persists to a rather great depth but gradually diminishes, until at a depth ranging from 3 to 4 feet or deeper, it becomes medium brown or slightly reddish brown, and the texture is loose coarse loamy sand or fine gravelly sand. In a few small areas the surface soil is underlain within a depth of 3 feet by a heavy red subsoil, and in other places the loose material extends to a great depth—at Parker station to a depth of more than 8 feet. The material from which this soil is developed is an alluvial-fan deposit of coarse angular sand and fine gravel—mostly granite and syenite.

Conditions for the growth of grass are ideal on this soil which absorbs and holds moisture well, releases it readily to the plants, and is sufficiently rich in humus and nitrogen to support a vigorous plant growth.

Tumacacori gravelly loam.—Tumacacori gravelly loam is similar to Tumacacori coarse sandy loam, but it contains a rather large quantity of gravel and stone and a finer grade of fine soil material than that soil. The texture of the fine-earth material ranges from medium sandy loam or fine sandy loam to fine-textured loam. This soil is dark brown or nearly black, is mellow and open, and at one time apparently supported an abundant growth of grass, although at present only small areas are in grass, mesquite being the predominating vegetation. In places the growth is very thick. Burroweed grows in many places.

This soil covers only small areas along Florida Wash. The soil materials are weathered from igneous rocks, including rhyolite and trachyte, which break down and produce a fine-textured soil material.

Tumacacori gravelly loam, stony phase.—The stony phase of Tumacacori gravelly loam is identical with Tumacacori gravelly loam, with the exception that it contains a large quantity of cobbles and boulders. It supports little grass, but much mesquite and hackberry, and some burroweed grow on it.

Tumacacori gravelly loam, shallow phase.—Tumacacori gravelly loam, shallow phase, is an inextensive soil, occurring largely north of Florida Canyon in the southeastern part of the experimental range. The surface soil is dark grayish-brown mellow gravelly loam very similar to typical Tumacacori gravelly loam, but it overlies an older, redder, and more compact subsoil at a depth ranging from 2 to 3 feet below the surface. The subsoil is reddish-brown or red tough compact gravelly clay loam.

This soil supports a rather thin stand of grasses and much burroweed and mesquite, although the color of the surface soil indicates a rather large content of organic matter, which is doubtless owing to a heavier grass growth in the past.

SOILS OF THE CAJON SERIES

The Cajon soils are developed from recent or comparatively recent alluvial-fan and intermittent stream-bottom deposits. The surface soils are of coarse texture, loose open character, and low organic-matter content. They are light brown or light grayish brown in color and are underlain by slightly lighter colored subsoil materials which are irregularly stratified. The parent materials are derived mainly from granitic or other quartz-bearing rocks, although, as occurring in the Tucson area, these soils represent a mixture of materials. They lack horizons of compaction or other soil development, are unleached, and in typical areas are mildly or feebly calcareous, the lime being uniformly distributed through the soil material.

Cajon sand.—Cajon sand consists of loose light grayish-brown or light brownish-gray coarse sand or coarse loamy sand developed on recent raw alluvial deposits having their source mainly from granitic rocks. It is leachy, of low moisture-holding capacity, and of little present or potential agricultural value. Compared with the Comoro and Tumacacori soils, it is of more recent accumulation, lighter in color, and lower in organic-matter content.

It occurs along desert washes and on alluvial fans in the valley part of the area, and as long narrow low-lying strips in Box Canyon, Melendreth Canyon, and along other intermittent drainage courses in the experimental range.

Some of the higher lying or moist areas support a fairly good growth of grasses, burroweed, scattered mesquite, and other desert shrubs. The lower lying areas in the valley support a growth of creosotebush, paloverde, ironwood, and a thin stand of fine-leaved grasses which furnish a small amount of grazing following the winter and summer rainy seasons.

This soil is cut at short intervals by drainage channels and is subject to disturbance, erosion, and redeposition. As mapped it includes some gravelly areas which are indicated on the map by gravel symbols.

A very narrow area of Cajon sand joins with a small body of Gila sand of the Nogales area, with which it was included. Cajon sand is much more extensively and typically developed in the Tucson area, in which it is recognized as conforming more closely to soils of the Cajon series.

SOILS OF THE ANTHONY SERIES

The Anthony soils have light-brown, light reddish-brown, or light grayish-brown surface soils which in general are not calcareous or only slightly so. The subsoils are distinctly or highly calcareous and are reddish brown or grayish brown. The soil materials are alluvial-fan deposits of variable texture, in many places considerably stratified. These soils are not extensive in the experimental range, occurring only in the lower and more arid part, but they are very extensive in the valley part of the area. They are covered largely by a shrubby growth consisting of mesquite, burroweed, and, in places, much creosotebush. A thin stand of perennial grasses grows on these soils in the southwestern corner of pasture no. 5 of the experimental range.

Anthony sandy loam.—In the valley part of the area, Anthony sandy loam occupies alluvial-fan slopes which border the Santa Cruz Valley from Continental on the south to San Xavier Mission, and in the northwestern part of the area, bodies lie east of Rillito, north of Marana, and along Avra Wash. Gravelly areas, shown on the soil map by gravel symbols, are present, here and there, on the alluvial fans lying on the west side of the Santa Cruz Valley between Tucson and the northern end of Tucson Mountains, and west of Avra Wash in the northwestern end of the area.

The valley areas are somewhat similar to the Gila soils, but have a somewhat redder and somewhat more compact subsoil, with more pronounced concentration of lime. The surface soil is light-brown or light reddish-brown sandy loam containing a high percentage of coarse angular sand and fine gravel, the gravel being more abundant and larger and the fine soil material lighter in color in the gravelly areas. Some of the gravel are coated with lime, but otherwise the surface soil material is generally leached of lime. The subsoil is irregularly stratified with materials ranging in texture from coarse gravelly sand to heavy loam. It is distinctly calcareous and has a pale-red color, with fine white veining of accumulated lime.

The areas of finer textured material of low gravel content take moisture readily, have fair or good moisture-holding capacity, and would be adapted to the same crops as the lighter textured Gila soils, were it not for the fact that they lie at too great a height to be irrigated economically. Because of the coarse texture and low water-holding capacity, the areas of gravelly soil are not well suited to cultivation. None of this soil is now under cultivation, and it is doubtful that any of it ever will be irrigated. It supports a growth of creosotebush, burroweed, and scattered mesquite, paloverde, and cholla cactus, with a few small annual herbs. It affords a small amount of grazing.

Anthony sandy loam, as occurring in the experimental range, has a vegetal cover consisting largely of burroweed and scattered mesquite and creosotebush, with a few areas of grass, including both annuals and perennials. *Muhlenbergia porterii*, *Aristida californica*, Rothrock grama, and cotton grass are prominent.

Anthony sandy loam, calcareous phase.—Anthony sandy loam, calcareous phase, occupies a very small area at the northern end of the experimental range. It is very similar to typical Anthony sandy loam but is grayer and is more highly calcareous both in the surface soil and subsoil. The surface soil is light grayish-brown or pinkish-brown medium or coarse sandy loam containing much gravel, and the subsoil is somewhat more compact light-gray or light grayish-brown coarse gritty material.

The principal vegetation at the lower elevations consists largely of creosotebush, together with a smaller amount of desert zinnia (*Cassina pumila*), but at the higher elevations creosotebush practically disappears, giving place to grasses, scattered mesquite, cacti, and yucca. Among the grasses are low tridens and several species of *Aristida*, as well as a number of annuals.

Anthony sandy loam, red phase.—The red phase of Anthony sandy loam occurs only in Avra Valley near the Silver Bell road east of Maish Knoll School. It occupies smooth areas on a low ridge which seems to be an old terrace of Santa Cruz River. The

land is not under cultivation but supports a good stand of grasses, filaree, and annual herbs, which afford considerable grazing after a rainy season.

This soil is similar to typical Anthony sandy loam, but it is redder in both the surface soil and subsoil. The subsoil is slightly more compact, although it is lighter textured and more friable than the subsoil in the Mohave soils. The soil has good water-holding capacity and would doubtless be a good agricultural soil under irrigation, when it would be well adapted to growing cotton and alfalfa, and probably, to less extent, hegari and the small grains.

Anthony gravelly sandy loam.—Anthony gravelly sandy loam occupies rather long narrow strips paralleling drainage channels in the lower western and northwestern parts of the experimental range. In most places the surface relief is ridgy, sloping, or dissected, and it is probable that erosion has removed much soil material, leaving the gravel concentrated on the surface. The surface soil is pinkish-brown or grayish-brown gravelly sandy loam or gravelly loam, which in most places ranges from moderately to highly calcareous. The subsoil is grayer than the surface soil, is slightly compact, and is highly calcareous.

The vegetation is rather sparse on most of this soil. It consists largely of creosotebush, burroweed, and low tridens grass, but on a number of rather steep slopes in the southwestern corner of pasture no. 5, the land supports a fair growth of perennial grasses including tanglehead, several species of *Aristida*, cotton grass, and a number of others.

Anthony loam.—Anthony loam is similar to Anthony sandy loam, but it has a somewhat finer and heavier textured surface soil, being a gritty loam. The valley areas occur on alluvial fans, in many places closely associated with Anthony sandy loam. None of this soil is under cultivation, but it would doubtless be a good agricultural soil, as it resembles Gila loam and would, like that soil, be well adapted to the common crops of the area, including alfalfa, cotton, grain sorghums, and the small grains, if water were available for irrigation.

The soil of a number of small areas included with Anthony loam differs from typical Anthony loam in that the surface soil is heavy loam, silt loam, or clay loam. In the valley these areas occupy somewhat lower ground than the other Anthony soils and lie at the foot of the alluvial fans. A small body south of San Xavier Mission contains a rather large quantity of "alkali" salts. Little or none of such land is under cultivation, but most of it would be productive if it were irrigated.

In the experimental range Anthony loam covers only very small areas and is of little importance for grazing. The surface soil has a tendency to slick or seal over during a rain and absorbs moisture rather slowly. Apparently this soil is not so favorable for the growth of grass as are the sandier soils, and it supports a very sparse grass cover. The vegetation is composed largely of burroweed and mesquite, together with scattered creosotebush.

Anthony loam, calcareous phase.—Anthony loam, calcareous phase, is somewhat similar to typical Anthony loam and its heavy-textured phase, but the surface soil seems to be a somewhat more

recent silty deposit which is distinctly or highly calcareous. The surface soil, to a depth ranging from a few inches to more than 2 feet, is light-brown, rather dark brown, or dull-brown fine silty loam. It is underlain by a somewhat irregularly stratified and, in places, gritty subsoil which is rather highly calcareous but free from decided compaction or cementation.

The vegetation consists of an almost pure stand of creosotebush, with a small amount of mesquite.

Anthony silty clay loam.—Anthony silty clay loam is developed in the northwestern part of the valley area along Avra Wash. It occupies the rather narrow flood plain of that wash and is occasionally overflowed after heavy rains, especially in the summer.

This soil is somewhat similar to Gila silty clay loam, but it shows more indication of soil development. Both surface soil and subsoil are redder and the concentration of lime in the subsoil is greater than in the Gila soil. The surface soil is light pinkish-brown or pale reddish-brown rather compact and cloddy silty clay loam which may or may not be distinctly calcareous. The subsoil is rather tough cloddy reddish-brown or dull-red silty clay loam. It is highly calcareous and has a fine veining or mottling of white lime carbonate, which is more pronounced in the lower part, below a depth ranging from 3 to 5 feet.

Nearly all this land is in its natural state, and much of it supports a dense growth of scrubby mesquite, together with scattered creosotebush and other small brush. Small tracts south of the Silver Bell road have been cleared, and a part of this land is in Johnson grass which is irrigated by summer flood waters and produces a hay crop, in addition to pasture for cattle and horses.

The depth to ground water is very great in this part of the area, otherwise it might pay to irrigate this soil which would then doubtless be somewhat similar in productivity to Gila silty clay loam.

SOILS OF THE SONOITA SERIES

The Sonoita soils are represented in the Tucson area by a single type, Sonoita sandy loam, which occurs only in the experimental range.

Sonoita sandy loam.—As occurring in this area Sonoita sandy loam is reddish-brown, rather dark rich-brown, or dull reddish-brown medium or coarse sandy loam. The surface soil ranges in thickness from 6 to 12 inches, or in a few places is thicker, and most of it has a neutral or slightly acid reaction. The upper part of the subsoil is reddish-brown or dull-red heavy sandy loam, loam, or gritty clay loam, which is rather compact and tough, especially when dry. The subsoil below a depth of about 30 inches is somewhat heavier, being in places gritty clay loam, and in other places gritty clay, and the material has a dull-red color. The lower part of the subsoil, below a depth of 3 or 4 feet, is grayer and faintly mottled or veined with gray lime carbonate.

This soil is rather extensive in the mesa and semidesert vegetation belts. It supports a good growth of grasses in many places, but in others it is covered by a rather heavy stand of burroweed and mesquite. It is probable that the killing out of grass by overgrazing allowed the shrub vegetation to obtain a start and it now dominates

the growth. A rather slight degree of erosion has taken place, but only in a few places has enough of the surface soil been removed to greatly lower the capacity of the land to produce grass. Among the grasses growing on this soil are Rothrock grama, several perennial species of *Aristida*, and cotton grass. Heavy erosion down to the tough red subsoil would render this soil inferior for grass production, but, on account of the comparatively smooth surface and fairly thick vegetal cover, erosion is severe in only a few small spots.

SOILS OF THE MOHAVE AND TUCSON SERIES

The Mohave and Tucson soils are the more maturely developed soils having soft caliche, which occur on the older alluvial fans and upland terraces. They have light reddish-brown or red surface soils, dull-red upper subsoil layers, and mottled gray and red compact highly calcareous softly cemented lower subsoil layers. They hold moisture well and are fairly pervious. A small area of the Tucson soils is cultivated and produces fairly good crops of alfalfa, cotton, grain sorghums, and small grains.

The Mohave soils have crop adaptations similar to those of the Tucson soils, but they are not under cultivation. They are rather extensively developed in the valley part of the area and occur in only a few small bodies in the lower part of the Santa Rita Experimental Range. They are similar to the Sonoita soils but are not so deeply leached of lime carbonate and other soluble compounds.

Tucson loam.—Tucson loam is one of the more extensive soils in the area and one of the most widely distributed. Only a small proportion, probably less than 10 percent, of the land is under cultivation. The cultivated land lies northwest of Tucson in the Flowing Wells district. A large part of the suburbs of Tucson are located on this soil. It does not occur in the experimental range.

Tucson loam has a light reddish-brown or dull reddish-brown surface soil composed of distinctly limy coarse gritty loam which contains much coarse angular quartz sand. The subsoil, below a depth of 1 or 2 feet, is rather compact cloddy gritty clay loam having a pronounced reddish-brown or dull-red color, mottled and streaked with gray lime carbonate. The deeper part of the subsoil, below a depth of 2½ or 3 feet, is light-gray or pinkish-gray compact softly cemented gritty material which when dry is rather hard but when wet softens readily and is permeable to water and plant roots. This soil contains less organic matter than the Pima or Gila soils and is somewhat less productive.

Alfalfa, cotton, hegari, barley, and corn are the chief crops, and some peaches, apricots, and figs are grown. Fairly good yields of these crops are obtained where sufficient irrigation water is available, but, owing to high cost of water and low crop prices, the cultivated acreage is decreasing. Acre yields of alfalfa range from 3 to 4 tons, or occasionally more, and of cotton from one-half to 1 bale.

In the virgin condition this soil is covered with a growth of creosotebush (locally known as greasewood), burroweed, scattered mesquite, and cacti (pl. 1, *B*) and in places supports a scattered growth of small fine-leaved grasses. Most of the land is easily and cheaply cleared and leveled, as it is smooth or gently rollling, well drained, and free from harmful quantities of salts.

Tucson gravelly loam.—The surface soil of Tucson gravelly loam is dull-brown or light reddish-brown distinctly calcareous loam, the surface of which is covered with a concentration of gravel. The upper part of the subsoil is rather compact pronounced reddish-brown gritty clay loam mottled and streaked with gray lime carbonate, and the lower part is light-gray compact softly cemented material.

This soil occurs only in the experimental range. The chief vegetation is creosotebush, and there is a small quantity of mesquite and burroweed. There is a rather heavy growth of low tridens, but practically no other grass. The presence of creosotebush and low tridens indicates a large amount of calcium carbonate in the soil.

Mohave loam.—Mohave loam is very similar to Tucson loam, but it is more red in both the surface soil and subsoil, and the surface soil is not calcareous. The upper part of the subsoil is tougher and more compact and probably contains a larger percentage of clay than the corresponding layer of Tucson loam.

The surface soil is light reddish-brown or dull-red gritty loam containing no free lime carbonate. The upper part of the subsoil is compact cloddy dark reddish-brown or dull-red gritty clay loam containing fine white mottling or veining of lime carbonate. The subsoil, below a depth ranging from 2 to 3 feet, is compact softly cemented material having a mottled uneven color ranging from reddish brown to almost white, and the material is of high lime content. Below a depth ranging from 4 to 6 feet, the material in places is somewhat softer, less cemented, and more red.

This soil is rather extensively developed south of San Xavier Mission and on the east side of the Santa Cruz Valley on rather smooth gently sloping alluvial fans. None of it is under cultivation, and no future agricultural development is probable, as it lies too high to be economically irrigated. If it were irrigable, it would be fairly well adapted to the production of the common farm crops of the area. In its natural state it supports a growth of desert sage, burroweed, creosotebush, and scattered mesquite and cacti.

In the experimental range, Mohave loam occurs in only a few small bodies along the western boundary. It supports a growth of burroweed, scattered mesquite and cholla, and a small amount of creosotebush in places. The grass growth is very sparse, although a few small annual grasses and weeds grow.

Mohave clay loam.—Mohave clay loam is similar to Mohave loam, but it is heavier in texture both in the surface soil and subsoil. The surface soil is clay loam of fine or gritty texture, and the subsoil is heavy clay loam or clay.

The largest body of this soil in the valley part of the area is in Avra Valley west of the northern tip of the Tucson Mountains. It occupies a large flat area at the foot of an alluvial fan and receives much surface run-off after heavy rains. Smaller bodies are around Tucson, occupying narrow flats along the natural drainage courses. This soil is practically free from "alkali" salts. The vegetation is largely creosotebush, small grasses, and mesquite.

Very little of the land is under cultivation, as most of it lies outside the zone of shallow ground water and, therefore, has no easily available water supply. A few small bodies northwest of Tucson

in the Flowing Wells district are devoted to alfalfa, cotton, barley, and pasture. The soil is well adapted to growing small grains and pasture grasses, and, although it gives fairly good yields of alfalfa and cotton, it is not so well adapted to these crops as are the Gila and other soils of lighter texture, which warm up earlier in the spring and absorb water more readily.

In the experimental range this soil occurs in only two small bodies along the western boundary. Here the vegetation is sparse, consisting largely of a scattered growth of mesquite and a small amount of burroweed and creosotebush.

Mohave clay loam, dark-colored phase.—Mohave clay loam dark-colored phase, is similar to typical Mohave clay loam, but it has a darker surface soil of dark-brown or dark grayish-brown clay loam or silty clay loam. This soil is similar to the McClellan soils of the Middle Gila Valley and other areas covered by the soil survey, and it would have been so mapped had it been more extensive. The surface soil is similar to that of the Pima soils.

This soil occurs only in the valley part of the area. None of the land is under cultivation. Under cultivation it would probably have a value somewhat similar to that of Pima silty clay loam and would doubtless produce good crops of barley, wheat, hegari, alfalfa, and cotton.

Mohave sandy loam.—Mohave sandy loam, although a rather extensive soil in the valley, has little importance as an agricultural soil in the Tucson area, perhaps 5 percent or less being under cultivation.

The surface soil is friable or loose light reddish-brown sandy loam, and the subsurface soil, to a depth of about 1½ feet, is dull-red compact sandy loam. Neither of these layers contains lime carbonate. The subsoil, to a depth ranging from 3 to 3½ feet, is compact cloddy dull-red heavy sandy loam or clay loam, somewhat mottled with white lime carbonate. The lower part of the subsoil is much grayer and is compact and softly cemented with lime.

This soil is very similar to Mohave sandy loam of the Salt River Valley area, where it is extensively and successfully devoted to alfalfa, cotton, small grains, grapes, citrus fruits, and a number of other crops. In the Tucson area small tracts have been devoted to alfalfa, cotton, and peaches, but the cost of water has caused abandonment of part of the cultivated land. In its virgin state this soil supports a growth of creosotebush, burroweed, small grasses, and alfileria, or filaree. In the lower end of the Avra Valley south of Marana, where grass and filaree grow almost to the exclusion of brush, the land furnishes a rather large amount of pasture after each rainy season.

Mohave sandy loam, dark-colored phase.—Mohave sandy loam, dark-colored phase, is very similar to typical Mohave sandy loam, but it has a somewhat darker surface soil and is somewhat more deeply leached of lime carbonate. The surface soil is reddish brown or dark reddish brown, the subsurface soil is dark reddish brown or dull red, the upper part of the subsoil, to a depth ranging from 2 to 3 feet, is red and not calcareous, and the lower part of the subsoil is gray and highly calcareous.

This soil lies on high sloping fans near Continental, and it cannot be irrigated economically. It supports a growth of burroweed and scattered mesquite, together with a small amount of cholla and other

cacti. Under irrigation, if this were possible, it would have a value similar to that of typical Mohave sandy loam.

SOILS OF THE LAVEEN SERIES

The Laveen soils belong to the group of gray calcareous soils. These soils have light-gray, pale reddish-gray, or pinkish-gray subsoils. Both the surface soils and subsoils contain large quantities of lime. Small irregular lime carbonate nodules are abundant in the surface soils, and they occur in the subsoils in great quantities, giving rise to a compact but nodular structure and soft cementation which softens further under irrigation and offers little permanent obstruction to percolation.

The Laveen soils are extensive in the valley, but only small areas are under cultivation. They respond to irrigation and cultivation in much the same way as the Tucson soils. They are of small extent in the experimental range, and they occur mainly in its northeastern part where the rainfall is low.

Laveen gravelly sandy loam.—Laveen gravelly sandy loam is the only important soil of the Laveen series in the experimental range.

There is a thin concentration of gravel and sand on the surface, beneath which the soil is highly calcareous light grayish-brown firm but friable sandy loam or gritty loam, with a distinct pink tinge. The surface soil extends to a depth ranging from 1 to 2 feet, in some places deeper, and it is underlain by a compact limy softly cemented subsoil which in most places is light gray or pinkish gray, although the upper part in many places has a decided red cast. In places the lower part of the subsoil is rather firmly cemented, resembling the hardpan, or caliche, layer of the Pinal soils.

At the lower elevations this soil supports an almost pure stand of creosotebush, with considerable desert zinnia in places, and in open spots a growth of low tridens. At the higher elevations the creosotebush disappears and is replaced by a rather thin growth of grasses and scattered mesquite, paloverde, and yucca. Among the more prominent grasses are low tridens, Rothrock grama, and *Aristida purpurea*. In places along the loose gravelly slopes of the arroyos a fairly good growth of grasses is present even in the lower creosotebush belt.

Laveen loam.—Laveen loam is another rather extensive soil which would be adaptable to cultivation were it not for the fact that it lies too high for economical irrigation. Little or none of it is used for crop production, but many small poultry ranches are located on it, on a few of which small plots are sown to alfalfa or grain to furnish green feed for the fowls, or gardens are planted to supply vegetables for home use.

This soil has a light reddish-gray or pale pinkish-brown gritty loam surface soil which is friable and granular and contains a high percentage of lime carbonate. Numerous hard lumps or nodules of lime carbonate are scattered over the surface and through the soil. The subsoil, to a depth ranging from 1½ to 2 feet, is similar to the surface soil but is slightly more compact and is underlain by very compact softly cemented light-gray or pinkish-gray nodular material. This layer has the appearance of a hardpan, or caliche, when

dry, but it softens readily when moistened and is permeable to moisture and roots.

Laveen loam occurs on gently sloping alluvial fans with a smooth or somewhat ridged surface, mainly in the valley part of the area. It supports a growth of creosotebush and scattered mesquite, with burroweed and desert sage in a few localities. It is free from harmful concentrations of "alkali" salts in most places, although a few small areas, as those on the edge of the Santa Cruz bottom lands south of Tucson, contain rather large quantities. However, as these bodies are not in an agricultural district, they are unimportant.

The Laveen soils in the Salt River Valley are used for the production of alfalfa, cotton, small grains, and truck crops, and they would doubtless be suitable for such crops here if furnished with an adequate supply of irrigation water. They are comparatively poor in organic matter and therefore somewhat less productive than the Pima and Gila soils. They need manuring and the growing of alfalfa, sweetclover, or other legume crops to maintain fertility.

In the experimental range this soil occurs in only a few small bodies associated with Laveen gravelly sandy loam, and it is very similar to that soil, except that Laveen loam is slightly finer in texture and practically free from gravel. Creosotebush makes up the greater part of the vegetation, and there is a small amount of mesquite.

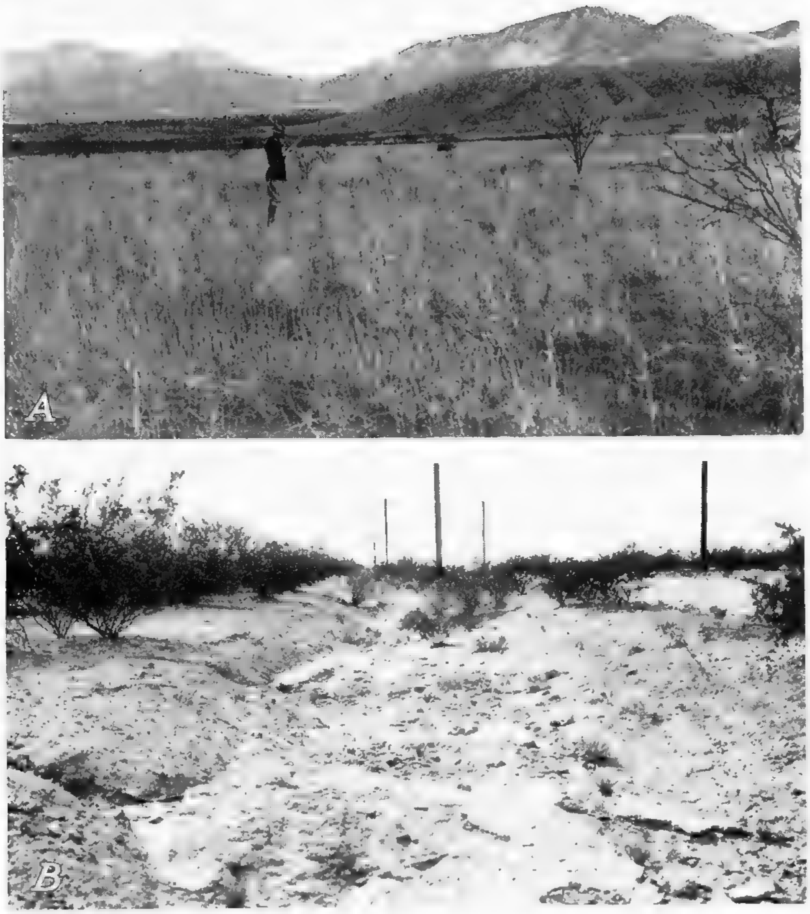
Laveen sandy loam.—Laveen sandy loam is very similar to Laveen loam, but it is somewhat lighter or coarser in texture. The surface soil ranges from sandy loam to loamy sand.

This is a less extensive soil than Laveen loam. It occurs in numerous small bodies around Tucson and more extensively in the northwestern part of the area between Santa Cruz River and Avra Wash. Very little of the land is under cultivation, as it lies on mesas or alluvial fans above the valley lands, and water for irrigation is not readily available. A few very small bodies northwest of Tucson are in alfalfa, pasture, and cotton, and, with sufficient water, this soil would doubtless produce fairly satisfactory yields of these crops. Like Laveen loam, it is low in organic matter which may be supplied by growing alfalfa and other legumes and by the application of barnyard manure.

As occurring in this area, Laveen sandy loam includes small bodies which contain a high percentage of gravel and stone. Such areas are indicated on the soil map by gravel symbols. They occupy rather uneven ridgy and dissected alluvial fans. None of this gravelly soil is under cultivation, and it has very little value for agriculture.

SOILS OF THE PALOS VERDES SERIES

The Palos Verdes soils occupy old upland fan areas and have a well-formed hardpan layer which is not so hard as that in the Pinal soils. They are used to some extent for growing citrus fruits, but it is necessary to break up the hardpan layer, in order that the tree roots and water may penetrate to lower more friable material.



A, Grassland vegetation on White House gravelly sandy loam occupying elevated alluvial-fan slopes on the Santa Rita Experimental Range, foothills of Santa Rita Mountains in distance. *B*, Caliche hardpan exposed in shallow drainageway in Pinal sandy loam.

A, Surface character and native vegetation on Tubac gravelly clay loam, ocotillo on left, cholla cactus on right; Santa Cruz Valley in distance. Note widely spaced plants and intervening barren spaces of desert pavement. *B*, Effects of erosion in soft uniform materials of the lighter textured Gila soils.

The Palos Verdes soils in the Tucson area are represented by a single soil type, most of which occurs in the northern part of the valley section.

Palos Verdes gravelly sandy loam.—Palos Verdes gravelly sandy loam is much like the Mohave soils in color and general appearance, but it has a harder, more firmly indurated subsoil which in most places is a true hardpan although not so hard as that in the Pinal soils. The surface soil is light reddish-brown coarse sandy loam or fine gravelly sandy loam with much of the coarser gravel and cobbles scattered over the surface. It is friable and does not contain lime carbonate. At a depth ranging from a few inches (or in a few places outcropping on the surface) to as much as 18 inches, is compact pale-red gritty loam or clay loam, cemented into a hardpanlike layer which, when dry, breaks into clods ranging from 6 to more than 8 inches in diameter. This material absorbs moisture readily and becomes somewhat softer, but it still resists crumbling. The cementing material seems to be largely iron oxide. At a depth of less than 2 feet is a mottled pale-red and gray lime-cemented hardpan which absorbs moisture slowly and softens very little when moist. At a depth of 3 feet or deeper is loose porous coarse sand or gravelly sand. The hardpan layers resist penetration of both water and roots and do not form a favorable medium for plant growth, but if holes are dug or blasted through the hardpan to the softer material below, drainage and room for root development are provided and trees may doubtless be successfully grown.

The most extensive development of this soil is on the high sloping alluvial fans at the base of Santa Catalina Mountains north of Tucson, and small bodies lie along the break of the lower terrace south of Rillito Creek and south of Santa Cruz River in Avra Valley.

Only a small acreage is under cultivation. On the Palos Verdes Orchards development, just west of the Oracle road 6 miles north of Tucson, a small acreage was planted to citrus (grapefruit and orange) trees in 1930. These trees made some growth and passed through the winter of 1930–31 without damage by frost. This particular locality, as shown by temperature records kept at the orchards, is considerably warmer than the lower land around Tucson, and, although it cannot yet be considered as fully demonstrated, it may prove to be sufficiently free from excessively low temperatures to allow the successful growth of citrus fruits. The depth to ground water is very great in this locality (about 240 feet). The cost of pumping water for irrigation will doubtless prove to be high and the supply limited. It is doubtful that any other crop than citrus fruits could be profitably grown on this soil. The soil is poor in organic matter, which may be supplied in the form of barnyard or green manures or in blood meal, cottonseed meal, or other commercial fertilizers.

SOILS OF THE WHITE HOUSE SERIES

The White House soils in their typical development have dark dull-brown, dark rich-brown, or chocolate-brown surface soils. Some included areas have a thin veneer of somewhat red material or the dark-colored surface soils have been eroded, exposing the redder underlying material. The surface soils are granular, comparatively

high in organic matter, and slightly acid. They are underlain by red or dark-red compact and tough heavy-textured subsoils which grade into lighter colored, or somewhat yellow, deeper material of less dense character, which in many places includes embedded boulders and gravel.

The White House soils occur on the more elevated alluvial-fan slopes near the foot of Santa Rita Mountains. The lower lying areas grade into the redder soils developed under lower rainfall, from which the White House soils are distinguished by their darker color, higher organic-matter content, more massive subsoils, and greater depth of leaching. The parent soil materials are derived mainly from granitic or other quartz-bearing rocks.

These soils occur only on the higher slopes of the Santa Rita Experimental Range. They are in general good soils for grass and contain in their dark surface soils the evidence of grass growth over a long period of time. The comparative thinness of the surface soils renders erosion especially serious, and, where the heavy red subsoil is exposed, conditions for plant growth are poor.

White House gravelly sandy loam.—White House gravelly sandy loam occupies the greater part of the large alluvial fan descending from Madera Canyon, and it all lies south of the drainage from Florida Canyon. It comprises more than 1,000 acres, nearly all of which has a good perennial grass cover (pl. 2, *A*). The vegetation includes curly mesquite grass, a number of gramas, species of *Aristida*, and tanglehead, also a scattered growth of mesquite, and in places where the surface has been disturbed by burrowing rodents, a small amount of burroweed. *Calliandra* is common on this soil.

Where typically developed this soil has a friable and granular dark dull-brown or dull reddish-brown surface soil. However, it includes areas in which there is a thin superficial layer of redder material or areas in which the dark-colored layer has been removed by erosion, exposing the red underlying material. At a depth of 8 or 10 inches is a tough red clay subsoil containing a large quantity of gravel, cobbles, and boulders. At a depth ranging from 4 to 6 feet the clay content of the soil diminishes, the content of stone increases, and in most places the soil material is distinctly calcareous, but in only a few places is the quantity of lime carbonate sufficient to impart a distinct gray color or to produce cementation. The surface soil and upper part of the subsoil are normally slightly acid or neutral in reaction.

Apparently erosion has not been severe on this soil, as the surface is protected by a good grass cover and by the large quantity of gravel and stone in the soil. Very shallow gullying has taken place to a slight degree, and at the lower end of such gullies a thin sheet of loose sandy material has been deposited. Tanglehead grass is the principal vegetation on such loose soil. Occurring as it does at a rather high elevation and in close proximity to the mountains, this soil receives a comparatively large amount of rainfall, and, although the subsoil is tough, moisture penetrates to a good depth—to a depth of 5 feet in March 1932.

White House gravelly sandy loam, stony phase.—White House gravelly sandy loam, stony phase, occurs in association with typical White House gravelly sandy loam on the fan sloping northwest

from Madera Canyon, where it occupies the higher stonier slopes and strips paralleling the drainage channels.

It is very similar to typical White House gravelly sandy loam, but it contains a higher proportion of cobbles and boulders. It supports a good stand of perennial grasses, principally curly mesquite and slender gramas, and *Calliandra*, ocotillo, and scattered mesquite are common. Little erosion is taking place on this soil, owing to the surface protection afforded by the stone and gravel and by the good grass cover.

White House coarse sandy loam.—White House coarse sandy loam is rather extensively developed throughout the central part of the experimental range, mainly in the mesa belt. It is an important grass-producing soil but does not, as a rule, produce such a thick stand of grass or such a heavy growth as do adjoining areas of Tumacacori and Comoro coarse sandy loams. The grasses are largely perennials, including Rothrock grama and other gramas and a number of species of *Aristida*. Burroweed and mesquite are plentiful in places, but in most places mesquite does not grow in a thick stand. The surface relief is smooth or somewhat ridgy, and the land is subject to some damage by erosion, especially on the steeper slopes where the surface soil is thinner and the stand of grass is less dense.

This soil in places has a thin surface veneer consisting of 1 or 2 inches of pale-red loose sandy material. Below this the topsoil, which in undisturbed areas ranges from 6 to 12 or more inches in thickness, is dark reddish-brown coarse sandy loam. The subsoil is tough dark-red heavy clay loam or gritty clay. Both the surface soil and the upper part of the subsoil are considerably leached, free from lime carbonate, and either slightly acid or neutral. At a depth of 30 or more inches below the surface the subsoil becomes somewhat lighter, or browner, in color and is distinctly calcareous, although in few places is the lime concentration sufficient to cause noticeable cementation or a distinct gray color.

White House coarse sandy loam, deep phase.—White House coarse sandy loam, deep phase, is much like typical White House coarse sandy loam, but it has a deeper and in most places a somewhat darker surface soil and is probably leached to a somewhat greater depth. It is not an extensive soil, but, occurring as it does in the upper part of the mesa belt and in the foothill belt, it supports a good growth of grasses, mostly perennials, including several gramas, species of *Aristida*, and tanglehead. In a small strip just north of Box Canyon, mesquite and burroweed predominate. Scattered live oaks grow near the foothills.

The surface soil, which in general ranges from 1 to 2 feet in thickness, is dark reddish-brown, very dark brown, or almost black coarse sandy loam containing a comparatively large quantity of organic matter. The subsoil is tough red clay loam or clay. This soil occurs in many areas where the surface soil is probably being slowly aggraded, or built up, rather than removed by erosion.

White House coarse sandy loam, stony phase.—White House coarse sandy loam, stony phase, is an important grass soil in the foothill belt. It is similar to typical White House coarse sandy loam and its deep phase, but, as it occurs on the higher, more steeply sloping,

rougher, and more deeply dissected alluvial fans, it is less uniform than those soils. The surface soil varies greatly in color, depth, and texture, as well as in the content of stone and gravel. In places where the surface is smoother and less subject to erosion, the surface soil ranges from 6 to 12 or more inches in thickness, is dull rich brown, or in places very dark dull brown, and is of coarse sandy loam or gritty loam texture. It contains a variable quantity of gravel, stones, and boulders. In the steeper areas the quantity of stone is greater, in many places occupying a large part of the surface. Much of the surface soil in such places is less than 6 inches thick, generally somewhat lighter colored or redder, and heavier in texture, but in only a few places is the very heavy red subsoil exposed.

This soil is covered in most places by a good stand of grass, though it is thinner on the stonier and shallower spots. The grasses include curly mesquite, the slender gramas, black grama, and, in places, tanglehead, and in most places there is a scattered stand of mesquite and a very small amount of burroweed. A few live oaks grow on the higher areas.

White House coarse sandy loam, steep stony phase.—White House coarse sandy loam, steep stony phase, occurs on the steeply sloping sides of arroyos, mainly in the central and upper parts of the experimental range. In many places it produces a good growth of perennial grasses, together with scattered mesquite, paloverde, cholla, pricklypear, and ocotillo. Among the grasses are curly mesquite, tanglehead, and several species of *Aristida* and grama.

This soil has little uniformity of profile. The immediate surface in many places is covered with a loose layer of gravel, cobbles, and boulders. The subsoil is variable, the tough red material, characteristic of the White House soils, in many places occurring near the tops of the slopes, but on the lower parts of many slopes the grayer limier material is exposed.

Grass often starts growing much earlier in the spring on the southward-facing slopes than on adjacent more level land.

White House gravelly loam.—White House gravelly loam in general supports only a very thin stand of grass, scattered mesquite, and burroweed, although there is a good growth of perennial grass in two fenced enclosures on the ridge about one-half mile north of Parker ranch.

The surface is covered by a thin pavementlike layer of red iron-stained gravel. The surface soil is dark-brown or dark grayish-brown gravelly loam or clay loam, with pronounced red inclusions, and averages about 6 inches in thickness. It is underlain by a tough subsoil of red clay loam or clay, containing embedded gravel and boulders. It is somewhat similar to the surface soil of White House gravelly sandy loam but is heavier in texture.

This soil can support a good growth of grass, as is indicated by the stand within the enclosures and the dark color of the surface soil, but it is so heavy that it absorbs moisture rather slowly and doubtless has a rather high wilting coefficient, hence it is not so favorable for grass growth as are the sandier White House soils. The surface is rather flat, and the soil has a tendency to become baked, forming a hard unfavorable condition for seed germination and plant growth.

White House gravelly loam, stony phase.—The stony phase of White House gravelly loam is inextensive. It occupies eroded areas,

and both surface soil and subsoil contain large quantities of stone and gravel on the surface and embedded in the soil material. The grass cover is sparse and the land is of slight grazing value.

SOILS OF THE CONTINENTAL SERIES

The Continental soils are related to the White House soils, with which they merge. They are developed on the lower alluvial-fan slopes which receive less rainfall, are of lighter reddish brown or dull-red color, lower content of organic matter, and have red subsoils of heavier texture and compact character. Although the surface soils are leached of lime and are generally feebly acid in reaction, the lower rainfall has resulted in less thorough leaching, and the lower lying subsoil material, at a depth ranging from 24 to 36 inches, is much mottled with accumulated lime. These soils are well drained and support semidesert shrubs and grasses.

These soils occur only in the Santa Rita Experimental Range and have a lower grazing value than the adjacent White House soils which occupy the more elevated areas and support a more abundant grass cover.

Continental sandy loam.—Continental sandy loam is pronounced reddish-brown or dull-red sandy loam ranging from a few inches to more than a foot in thickness. In most places it has a thin pale-red surface veneer of loose sandy material. The subsoil is tough red clay loam or gritty clay, which contains a large quantity of gravel and stone, and the lower part of the subsoil, at a depth of 2 feet or more below the surface, is lighter reddish brown calcareous gravelly clay loam.

This soil is fairly extensive in the lower part of the experimental range, occurring along the highway between Continental and Florida station. It produces a rather thin stand of grasses in most places, burroweed and mesquite predominating, although in a few places there is a good growth of perennial grasses.

Continental gravelly loam.—Continental gravelly loam might be considered a thin or eroded phase of Continental sandy loam. It has a profile similar to that soil, except that the surface soil is thinner, finer in texture, and contains much gravel and stone. The surface soil is heavy sandy loam or loam only a few inches thick, and it is underlain by a tough red heavy clay loam or clay subsoil which contains a very large proportion of gravel, cobbles, and boulders.

In most places the land supports very little grass. There is a rather sparse stand on some of the higher areas. Mesquite and burroweed form the predominant cover.

This soil absorbs moisture much less readily than the sandier soils, undoubtedly has a rather high wilting coefficient, and is not a favorable soil for the growth of grass.

Continental gravelly loam, stony phase.—Continental gravelly loam, stony phase, which is not extensive, occurs on ridgy areas, where considerable erosion has occurred in past times. It is similar to typical Continental gravelly loam but contains a larger quantity of stone. It has very little grass cover, and the most prevalent plant growth is a mixture of cholla, paloverde, mesquite, burroweed, and ocotillo.

SOILS OF THE PINAL SERIES

The Pinal soils are shallow calcareous light-gray, grayish-brown, or pale reddish-brown soils overlying lime-cemented hardpan, or caliche. They cover a large extent of country in the valley part of the Tucson area but in the experimental range occur only in comparatively small bodies in the northeastern and southwestern corners. They have little value for farming or as grassland.

Pinal gravelly sandy loam.—Pinal gravelly sandy loam is developed on the high, rather rough, dissected, and, in places, steeply sloping fans northwest, west, and south of Tucson, and north of Rillito Creek above the Sabino Canyon road, and it occurs on high ridges dissected by arroyos in the Santa Rita range. It has a light pinkish-brown or grayish-brown gravelly or stony sandy loam surface soil which ranges in thickness from a few inches to 3 feet. This layer is underlain by a gray lime-cemented hardpan, or caliche, which contains a large quantity of gravel, in most places very hard, and resembles a conglomerate or concrete. Typically, the hardpan is well developed and firmly cemented, resembling a conglomerate, but it is somewhat intermittent and, in spots, is fragmentary, soft, or partly formed. It has a somewhat platelike structure, ranges from a few inches to several feet in thickness, and overlies a substratum of gravel and stone into which lime has infiltrated, causing more or less cementation.

None of this soil is under cultivation, and it would have very little agricultural value, although it might be used for the production of citrus fruit in places, if sufficient water were obtainable. It would be necessary to dig or blast deep holes for planting the trees, and it is doubtful that they would make a very vigorous growth.

This soil supports a scattered growth of paloverde, creosotebush, mesquite, catclaw, ocotillo, and cholla, giant, barrel, and pricklypear cacti, and in many places has a fair covering of low tridens but little other grass growth.

Pinal gravelly sandy loam, steep phase.—Pinal gravelly sandy loam, steep phase, is similar to the typical soil, but it occurs on steep hillsides or slopes bordering the intermittent stream channels or arroyos. It occurs only in the experimental range. The hardpan layer is less regular than in the typical soil, in many places being fragmentary and broken and in some places absent.

On these slopes, besides the scattered desert shrubs, there is a rather heavy cover of perennial grasses, including low tridens, tanglehead, *Aristida purpurea*, *A. californica*, and others.

Pinal gravelly sandy loam, red phase.—Pinal gravelly sandy loam, red phase, occupies a small area in the northeastern corner of the experimental range. It is similar to typical Pinal gravelly sandy loam, but the surface soil is reddish brown or dull red, and the hardpan, which lies only a few inches below the surface, although mainly gray, is stained and mottled with red.

This soil supports a heavy stand of low tridens, but little other grass, also much desert zinnia, pricklypear, and cholla, and scattered mesquite, paloverde, and ocotillo.

Pinal gravelly sandy loam, dark-colored phase.—Pinal gravelly sandy loam, dark-colored phase, is similar to typical Pinal gravelly sandy loam, but it is much darker and is higher in content of organic

matter. The surface is covered with a ½-inch accumulation of lime-coated gravel and light-gray coarse sand. The surface soil is friable granular dark grayish-brown sandy loam or gritty loam, which is highly calcareous and well supplied with organic matter. It is only a few inches thick and overlies a lime hardpan.

This soil, which occurs only in the experimental range, supports a fairly good growth of *Aristida purpurea* and low tridens, and a scattered brush growth consisting of mesquite, paloverde, and desert zinnia.

Pinal gravelly sandy loam, rock-outcrop phase.—Pinal gravelly sandy loam, rock-outcrop phase, is a shallow soil developed on limestone buttes and foothills in the northeastern part of the experimental range. To a depth of a few inches it consists of dark grayish-brown granular friable loam which contains much gravel and stone. Rock outcrops are numerous. In appearance and profile this soil is very much like the dark-colored phase of Pinal gravelly sandy loam.

The land supports a good growth of low tridens and a tall Triodia, as well as a number of other perennial grasses, and there are scattered plants of ocotillo, yucca, paloverde, mesquite, catclaw, and pricklypear.

Pinal sandy loam.—Pinal sandy loam is an extensive soil which occupies the greater part of the mesa land on which the city of Tucson is situated and large areas north, east, and south of the city. It occurs on high-lying land having a smooth, gently rolling, or ridged surface relief, which constitutes the remnant of a very old terrace or alluvial fan now lying at a higher elevation than the surrounding land.

This soil is characterized by a firmly cemented light-gray or almost white lime hardpan, or caliche, which has a covering of light grayish-brown or pinkish-brown coarse sandy soil (pl. 2, *B*). This covering ranges in thickness from a few inches to as much as 3 feet, and outcrops of hardpan occur in many places. The texture ranges from gritty loam to coarse sandy loam, in many places containing a rather large quantity of gravel and chunks of caliche. The hardness of the caliche layers differs greatly. In places this material is softly cemented, but in most places it consists of a very hard capping layer ranging from a few inches to 2 feet in thickness. Beneath this layer the material is somewhat softer, and at a depth between 3 and 6 feet it is a much softer slightly cemented coarse sandy or gravelly material, although in places the hard material may extend to a greater depth.

This is a very inferior soil for the growth of plants. The surface soil is poor in organic matter, humus, and nitrogen, dries out quickly in most places, and is not of sufficient depth to allow adequate room for root development. It is not used agriculturally to a great extent. A number of small poultry ranches are located on it, and on these a few small plots of alfalfa or other greens are grown for poultry feed, and a few small family gardens are maintained. In Tucson and its suburbs, where trees or shrubs are to be grown, holes are dug or blasted through the hardpan, and these are filled with good soil (Gila or Pima soil) hauled from the bottom lands along Santa Cruz River or Rillito Creek. The good soil is also spread over the surface where lawns or gardens are to be grown. The native vegetation consists

largely of creosotebush, together with a scattered growth of stunted mesquite.

Pinal sandy loam, deep phase.—The deep phase of Pinal sandy loam includes a number of small bodies north, east, and south of Tucson in which the hardpan lies at a greater depth than in typical Pinal sandy loam. The soil covering ranges from 1½ to 3 feet in thickness, or in places more. The texture ranges from sandy loam to loam, but in a few low flats east and northeast of the United States Veterans' Hospital it is clay loam, has a red color, and closely resembles Mohave clay loam, but it differs from that soil in that it is underlain by a firmly cemented hardpan.

This soil is not farmed and can hardly be considered a good agricultural soil, but it has sufficient depth to allow the growing of trees, lawns, and gardens without hauling in other soil.

SOILS OF THE TUBAC SERIES

The Tubac soils, developed on old upland fans, have tough, heavy red subsoils. They are not under cultivation, and there seems to be little probability that they will be developed. They are similar to the Continental soils, but, as they occur in lower drier locations, they produce less grass, have a lighter color, a lower organic-matter content, and are less deeply leached.

The surface soils are dull reddish brown or dull red and in places have a thin veneer of loose pale-red material. The subsoils are red tough heavy clay loams or clays of columnar structure. Lime carbonate occurs in the subsoils at a depth ranging from 1 to 3 feet below the surface, and the deeper parts of the subsoils are generally gray and are more or less cemented by lime which in places forms a true lime hardpan, or caliche.

Tubac sandy loam.—Tubac sandy loam is developed on the high gently sloping alluvial fans on the east side of the valley of Santa Cruz River northeast, east, and south of Continental, occurring in both the valley and the range parts of the area. A few small bodies are east of Tucson south and southwest of Wrightstown School.

The surface is smooth or slightly ridgy. The soil supports a native vegetation composed largely of burroweed, mesquite, a small quantity of cholla cactus, a scant growth of grass, mostly annuals, and a few annual weeds. The rainfall on this soil is low, and this is, probably, largely responsible for the comparative lack of grass. None of the land is under cultivation.

The 3- to 12-inch surface soil is dull reddish-brown friable sandy loam, and the upper subsoil layer is dark-red tough clay which breaks up into prismatic clods. Although the clay absorbs moisture slowly, the cracks between the clods allow water to penetrate to the lower layers. The surface soil and upper subsoil layers contain no lime carbonate, but below a depth ranging from 12 to 18 inches the soil material is distinctly limy and consists of dark reddish-brown or pale-red compact cloddy clay loam mottled with gray lime carbonate. At a depth of 3½ or 4 feet is a layer of mottled light reddish-brown and light-gray gritty loam which is compact and softly cemented by lime carbonate. Below this, in many places, the subsoil is redder and less compact.

This soil lies too high above the valley to have water available for irrigation. The characteristics of the soil suggest that, under cultivation, it would be somewhat similar to Mohave sandy loam or Mohave loam and could probably be used for the crops commonly grown. However, satisfactory irrigation might be hindered by the heavy subsoil.

Tubac clay loam.—Tubac clay loam is similar to Tubac sandy loam, except that it is heavier. This soil occurs in the same general location as Tubac sandy loam on the alluvial fans on the east side of Santa Cruz Valley near Continental, where it occupies mainly the smoother and more gently sloping fans at a somewhat lower elevation than Tubac sandy loam. Small bodies are west of Pantano Wash near Wilmot Road, and along the Silver Bell Road in Avra Valley. This is not an extensive soil in the experimental range, where it occurs in only a few small bodies in the northwestern corner.

This soil is similar to Tubac gravelly clay loam, except that it is practically free of gravel and stone. The materials of fine texture, from which it has been derived, were deposited by the slowly moving drainage water on the lower flatter land at the foot of the more steeply sloping fans.

The vegetation consists of a rather scattered growth of mesquite and burroweed and a scant growth of annual weeds. Many spots are barren. Although it occurs in rather smooth areas, this soil is becoming rather severely gullied in places.

All of this soil is outside of the present agricultural area and lies higher than the cultivated land, and there is little probability of its agricultural development. Under cultivation, it would doubtless be somewhat similar to Mohave clay loam but somewhat inferior to that soil because of its tougher and less pervious subsoil. It provides a small amount of grazing.

Tubac gravelly clay loam.—Several areas of Tubac gravelly clay loam occur in the southwestern part of the experimental range near Continental and in the northeastern corner near the Johnson ranch. They occupy very old gravelly fans which have been deeply cut by drainage channels into a series of flat-topped ridges, on which are the only normal developments of soil. On the slopes the surface soil and upper subsoil layers have either been eroded or have not developed as on the flats, and the gray calcareous material, normally occurring in the deeper part of the subsoil, is exposed at the surface.

In the valley part of the area this soil is more widely distributed than Tubac sandy loam and Tubac clay loam. It occurs in rather smooth areas on gravelly alluvial fans in the southern end, from the Santa Cruz County line north to Continental and Hartt, and west of Santa Cruz Valley from the vicinity of Tucson to the northern end of Tucson Mountains (pl. 3, *A*).

This soil has a thin desert pavement, or surface concentration of gravel, many of which are stained red, dark brown, or almost black. The surface soil is red, dull-red, or reddish-brown gritty clay loam or heavy gritty loam, containing much gravel. When dry it is hard and tough. It has a neutral or slightly acid reaction. The upper subsoil layer, which begins at a depth ranging from 2 to 8 inches below the surface, is tough dark-red heavy clay loam or clay, which

is neutral or slightly alkaline in reaction. Below an average depth of 18 inches the subsoil is similar in texture and structure, slightly lighter in color (brick red), and distinctly calcareous. At a depth of about 30 inches the material becomes much more highly calcareous and is mottled with gray lime carbonate. It grades into a light-gray or pinkish-gray more or less cemented layer, or caliche. The degree of cementation differs locally and appears to be greater, on an average, in the northeastern corner of the experimental range.

This soil absorbs moisture slowly and doubtless sheds a large amount of the rainfall, especially that of the violent summer storms. In the flatter places water may stand on the surface for a long time, driving the air out of the soil and causing the formation of a hard-baked crust which is very unfavorable for the germination and growth of seedlings. The wilting coefficient is high, that is, there must be a relatively high percentage of moisture in the soil before any is available to plants, because the soil holds much of it in an unavailable form. On account of the sparse vegetation and gravel pavement the temperature of the surface soil becomes very hot in midsummer, and this constitutes another unfavorable condition for the growth of plants.

Very little grass grows on this soil. The characteristic vegetation consists of ocotillo, cholla, barrel, and pricklypear cacti, with a few scattered paloverde, catclaw, mesquite, and burroweed. Many areas are nearly barren of vegetation. The only common herbaceous plant is a small purple composite (*Aster* sp.) which grows in the spring. Perennial grasses grow only on very small spots where the surface is covered with comparatively loose material, owing to the work of burrowing rodents or the accumulation of loose sandy or gravelly material through deposition by wind or water. On the slopes into the arroyos the surface has been disturbed by erosion, much of the finer material has been removed, and a loose mulchlike layer of gravel and stone remains, which seems to favor the growth of grass. Such slopes in general do not have the typical Tubac profile but are generally grayer, more calcareous, lighter in texture, and more friable in consistence. Where of sufficient extent they are mapped as the steep phase of Pinal gravelly sandy loam.

It is doubtful that this soil has produced much grass within recent times, and probably it will be hard to establish a good growth of grass, though it is barely possible this might be done by providing a period of complete protection from grazing. The land lies too high for irrigation and will probably never be cultivated. It is an inferior soil because of its high content of gravel, its tough subsoil, its low content of organic matter, and its high wilting coefficient.

A very small area of this soil joins with Tubac gravelly sandy loam of the Nogales area on the south, in which bodies of Tubac gravelly clay loam were included with Tubac gravelly sandy loam, owing to their small extent.

Tubac gravelly clay loam, stony phase.—Tubac gravelly clay loam, stony phase, is practically identical with typical Tubac gravelly clay loam, except that it contains a larger quantity of boulders and cobbles. It occupies small ridgelike areas in the lower end of the experimental range near Continental.

The vegetation is largely paloverde, cholla, and ocotillo. Grass is practically absent, and the only herbaceous growth consists of spring-growing annuals.

SOILS OF THE CORONADO SERIES

The Coronado soils are shallow soils developed on rocky buttes and foothills in the eastern and southeastern parts of the experimental range. They range from rich brown to dark reddish brown, or, in some places, dark brown in color. The subsoils, where the soil material is of sufficient depth, consist of red gritty clay loam similar to that of the White House and Tubac soils. Roots of grasses and shrubs have penetrated to considerable depth into bedrock which in most places is soft and easily crumbled in the topmost 1 or 2 feet. The rocks, from which the parent material has weathered, consist of granite, syenite, rhyolite, trachyte, or other related igneous rocks. These are good soils for grass.

Coronado stony coarse sandy loam.—Coronado stony coarse sandy loam is developed on hills composed of granite or syenite. These rocks weather to form a coarse gritty parent material for soil. The depth to bedrock ranges from nothing to more than 1 foot, and rock outcrops are numerous. On account of the steep rough surface relief, soil development is not uniform, erosion is severe in places, and the soil profile is variable and in many places not well developed. In some places the material consists of comparatively raw disintegrated granite to a depth of a few inches, whereas in other places there is a definite surface soil consisting of reddish-brown or dark reddish-brown coarse sandy loam a few inches thick, and a red gritty clay loam or heavy loam subsoil overlying soft crumbling granite or syenite, into which red colloidal material has penetrated. The whole mass is thoroughly impregnated with rust-red iron oxide. This color penetrates to a depth of more than 2 feet in places, and plant roots extend to a depth of more than 18 inches into the rock crevices.

A good stand of perennial grasses, including curly mesquite, slender gramas, side-oats grama, tanglehead, and various species of *Aristida*, commonly grows on this soil. *Calliandra* is plentiful, and in places there is a small amount of mesquite and live oak. On account of the steepness and stoniness of this land, it offers some difficulty to grazing and, doubtless, some protection to the grasses.

Coronado stony loam.—Coronado stony loam is similar to Coronado stony coarse sandy loam but is darker and finer. It is derived from rhyolite, trachyte, or other related igneous rocks which break down to form a finer textured soil material than does granite. It occupies only a small area of hill land in the southeastern corner of the experimental range.

The land supports a good growth of perennial grasses, prominent among which is curly mesquite. There are also a few scattered mesquite trees.

MISCELLANEOUS LAND TYPES

Rough broken and stony land.—Rough broken and stony land, as mapped in this area, includes areas so steep, rough, and badly eroded that they would have little or no agricultural value even if supplied with irrigation water. They are very stony or gravelly

and have developed little or no soil profile. Small areas of bare rocky mountains or hills are included in this class of land as mapped, but the larger areas consist of stony or gravelly alluvial fans which have been badly cut by erosion. If given a soil designation, the material probably would be classed with the gravelly Pinal and Laveen soils. The subsoil material, which is exposed on the surface in many places, is highly calcareous and more or less firmly cemented.

River wash.—River wash consists of the loose sandy, gravelly, and stony materials in the beds of intermittent streams and drainage channels. It is so coarse, loose, and leachy as to be valueless as agricultural land, and it is subject to overflow and shifting of the materials at more or less frequent intervals. Much of this land is bare, but in places it supports a growth of mesquite, catclaw, scattered specimens of yucca and desertwillow (*Chilopsis linearis*), burrobrush (*Hymenoclea monogyra*), and a few small patches of annual grasses.

EROSION

The southwestern desert region, in which the Tucson area lies, affords abundant visual evidence of the processes of erosion, much of which is the result of the normal and natural building of desert-land features. Steeply sloping land having soils low in organic matter and with an erosive physical character, located in a region subject to periods of brief but violent rainfall, is subject to destructive erosion if the soil is unprotected by vegetation. In some places, erosion has been accelerated by overgrazing and mismanagement of range or forest accompanied by wide-spread channel cutting, or entrenching, by the main drainage streams of undetermined but considerable geological significance. Evidence of this is pronounced in the Tucson area, especially in the vicinity of San Xavier Mission, where the channel of Santa Cruz River has been greatly deepened, or lowered, since the advent of irrigation, rendering ineffective or impossible the diversion by gravity of water for irrigation purposes. Deepening of the stream channels has been accompanied by erosion and sloughing of soil from the vertical banks, which is particularly pronounced in the uniformly fine textured Gila soils (pl. 3, *B*) and, to less extent, in the Pima soils. The eroded areas occur almost entirely as narrow strips adjacent to the stream channels, but they are becoming progressively enlarged in the Gila and Pima soils which are the most productive and most extensively farmed soils in the area.

Transitory or intermittent streams traversing the alluvial-fan slopes are subject to erratic and violent floods, and at irregular intervals, they shift, widen, deepen, or abandon their old courses for new courses, in many places eroding large areas of adjacent soils which, although extensive, are confined mainly to the desert slopes and are of little agricultural importance. On the more elevated alluvial-fan slopes, particularly where the older soils with tough compact subsoils have developed, sheet erosion, or stripping of the surface soil material, is of wide-spread occurrence, where the soil is not well protected, and of great economic significance in relation to the grazing of livestock.

As previously stated, most of the soils of the Santa Rita Experimental Range are developed from alluvial-fan deposits—that is, deposits of material eroded from the mountains or higher lying

alluvial fans and redeposited by drainage waters as long cones or fan-shaped slopes. Under natural conditions a constant round of alternate cutting and filling goes on in such deposits, but if the surface is exposed, through removal of the vegetal cover, especially the grass, the soil material is subject to much more rapid washing, and, with less vegetation to retard the run-off the redeposition of transported material is less probable and less heavy.

The factors influencing the rate of erosion are numerous, among the more important being the density and character of the vegetation, the quantity and distribution of rainfall, the slope of the land and its position relative to drainage channels, and the physical character of the soil.

According to Cooperrider and Hendricks,[7] a thin cover of trees or shrubs is much less effective in preventing excessive run-off and erosion than is the thicker cover provided by grass.

The slope of the land in the experimental range ranges from moderate to steep, and in most places is sufficient to cause rather rapid movement of water over any uncovered surface. This condition is conducive to rapid erosion but is not so pronounced as in many more mountainous sections.

The texture of the soil has a large influence on the rate of erosion, the finer material, free from coarse sand, gravel, and stone, cutting away more quickly than the coarser material. This doubtless explains the resistance to erosion of large parts of the steep gravelly and stony alluvial fans in the experimental range, and it is well known that gravelly soils become gradually more gravelly as the finer textured soil material is removed, causing an extreme concentration of gravel on the surface, and in places this forms a practically unbroken surface covering, commonly referred to as "desert pavement." Such a desert pavement is present on much of the surface of Tubac gravelly clay loam, and it occurs in somewhat less highly developed form on surfaces of the White House and Continental gravelly loams.

The deep, rather loose sandy loams and coarse sandy loams of the Comoro and Tumacacori series, which are derived largely from weathered granite, through very rapid absorption of rainfall minimize excessive run-off, and the coarse materials concentrated on the surface are not readily moved by drainage water; but these coarse materials are readily cut away wherever a large flow of water is concentrated, especially where drainage water originating in higher country flows across them. In the low-lying northwestern corner of the experimental range, where the slope is much less and the flow of water slower, severe gully erosion of some of the finer textured soils is common, as these soils absorb rainfall more slowly, shed much of it through run-off, have little grass cover, and erode easily.

On the Tubac, White House, and Continental soils, with their heavy tough red subsoils, and on the Coronado soils, with their steep slopes and slight depth to bedrock, erosion has a much more serious effect than on such soils as those of the Comoro and Tumacacori series, which are loose, friable, and well supplied with organic matter to considerable depth.

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[7] Cooperrider, C. K., and Hendricks, B. A. SOIL EROSION AND STREAM FLOW ON THE UPPER RIO GRANDE WATERSHED IN RELATION TO LAND RESOURCES AND HUMAN WELFARE. U. S. Forest Service, unpublished manuscript.

IRRIGATION, DRAINAGE, AND "ALKALI"

Farming without irrigation is impractical in this area, as the rainfall alone is not sufficient for the growth of crops, although it is of some use as a supplement to irrigation. The water supply is the limiting factor in the agricultural development of this area. Other than small quantities of water diverted from Santa Cruz River above San Xavier Mission and at Tucson and occasional summer flood water diverted onto small bodies of land, irrigation water must be pumped from wells. The underground water supply is limited and in most places has been fully exploited. On the Cortaro farms project around Cortaro, Rillito, and Marana, the water supply has apparently been overdrawn, as the water level has lowered since irrigation was started. The acreage under cultivation on this project has been decreased recently, and if it is held at or below the present acreage, the water supply probably will be sufficient. Much the same condition exists southwest of Tucson along Santa Cruz River. The rapidly growing city of Tucson has numerous wells here, and the increasing demand for municipal water supply is lowering the water level, making the abandonment of some of the farming land imperative. The increased demand on the limited water supply is bound to cause still further diminution of the cultivated land in the vicinity of the city.

The water in the river and in wells in this area contains appreciable quantities of salts, although in few places in sufficient quantities to make it harmful for irrigation if properly used. According to Catlin (*4*), most of the waters of the Santa Cruz and Rillito Valleys range from 16 to 200 parts of salts per 100,000, most of them containing less than 100 parts per 100,000. The water from only 2 wells of the 69 listed showed more than 200 parts per 100,000.

Care is necessary in irrigating with these waters, especially those which carry the higher salt concentrations, in order to prevent harmful accumulation of "alkali" in the soils. Continued furrow irrigation tends to produce a surface concentration of salts, and an occasional heavy flooding is advisable to dissolve the salts and carry them down through the soil and into the underdrainage. This is easily accomplished on the soils with open subsoils, but it is more difficult on soils with heavy or tough subsoils.

Drainage is in general well developed in this area, and consequently, under natural conditions, the accumulation of salts has not been extensive. Comparatively small areas in the Santa Cruz River bottom lands have become charged with salts, and probably most of the salt content is due to the capillary rise of water from a former high water table. Smaller areas along Rillito Creek above the mouth of Sabino Creek are slightly affected by salts, owing to high ground water. Small bodies have also become affected through improper irrigation with alkali-charged waters.

Tests were made by electrolytic-bridge method for the total salt content of soil samples taken throughout the Tucson area, but more especially in localities which gave some evidence of the presence of salt accumulation. Such evidence consisted, for the most part, of the character of the vegetation or the absence of vegetation. Plants which give evidence of salt-affected soils are seepweed (*Dondia* sp.) narrow-leaved saltbush (*Atriplex linearis*) and desert sage or saltbush (*Atriplex polycarpa*). Mesquite, although

tolerant of alkali, grows where moisture conditions are favorable, whether or not salt is present. The presence of creosotebush (*Covillea tridentata*), commonly called greasewood, is an indication of practical freedom from an accumulation of "alkali" salts.

Samples tested were taken by 1-foot sections to a depth of 6 feet. Results indicating the approximate content (percentage) of total salts in the air-dry soil are shown on the accompanying soil map as follows: (1) Location of sample; (2) percentage of salt content to a depth of 1 foot, shown by the upper figure of the fractional form; and (3) average salt content to a depth of 6 feet, shown by the lower figure. For example, the numerals $\frac{0.26}{0.19}$ indicate a concentration of 0.26 percent of salts to a depth of 1 foot and an average of 0.19 percent of salts to a depth of 6 feet at the point indicated on the map at which the sample was taken.

In mapping the concentration and distribution of "alkali" or salts, three grades of salt concentration are indicated. Areas which do not contain sufficient salts to be harmful to plants, generally less than 0.2 percent, are considered "alkali free" and are indicated by the letter F. Areas containing slight or moderate salt concentrations, ranging from 0.2 to 0.7 percent, which may be more or less harmful to crop plants but do not, as a rule, prevent their growth, are shown by the letter S. Areas strongly affected by "alkali," which must receive special treatment for reclamation before they may be successfully used for crop production are designated by an A. Such areas contain from 0.7 to 3 percent or more of salts.

Qualitative tests for "black alkali" salts (sodium carbonate) were made with phenolphthalein solution. The "alkali" in the Santa Cruz River Valley contained only traces of such salts, whereas that along Rillito Creek gave definite tests for carbonates. However, as the total salt content of the soils on Rillito Creek is low, the sodium carbonate content in most places is not considered prohibitively high.

SOILS AND THEIR INTERPRETATION

The soils of the Tucson area represent several stages in degree of development, or maturity. They have developed under three rather distinct zones, or provinces, of environment. The zones of environment are, however, by no means sharply defined one from the other but merge or intergrade through indefinite stages of transition. Dominated by differences in rainfall, temperature, and vegetation, they are correlative with differences in physiographic development.

These three main environmental zones are identified with three physiographic features as follows: (1) The broad upland alluvial fans which emerge from canyon mouths in the foothill and mountain fronts and slope steeply in the upper parts but with decreasing gradient downward toward the main valley drainage trough. The upper and more elevated parts of these fans are subject to relatively high rainfall and lower temperatures, and are dominated by grassland vegetation, with scattered areas of annuals and shrubs. (2) The alluvial valleys of Santa Cruz River and its tributaries, mainly Rillito Creek, which form the lowland parts of the area, and to which agricultural development, owing to the availability of water for irrigation, is confined. This is the desert section characterized by low rainfall

and high temperatures. (3) The lower and flatter slopes of the alluvial-fan areas, in which rainfall decreases rapidly with decrease in elevation. This zone represents a transition between the two zones described. It is a semidesert zone dominated by desert-shrub vegetation, but which may support scattered patches or larger areas of grasses.

The soils of the lower lying valley part of the area have been developed under southern desert conditions, in which the mean annual rainfall is about 11 inches, the mean annual temperature about 67° F., and a desert-shrub vegetation prevails.

Like the soils of other areas previously mapped in southern Arizona and other parts of the arid Southwest, the soils have certain general characteristics in common. The more mature soils are highly oxidized and are predominantly distinctly red or have a somewhat red tinge, but the red color in many of the soils is masked by the gray color imparted by lime carbonate. These soils contain little organic matter, as a rule not enough to materially affect the soil color. They are but slightly leached and contain a comparatively high percentage of salts of the alkali and alkaline-earth groups. Lime carbonate is present in most of these soils, and in many of them the content of soluble sodium and potassium salts is large. The lime carbonate forms a definite layer of accumulation, in many places being cemented into a hardpan, or caliche, in the more mature soils (pl. 2, *B*); although in some of the mature soils the surface soil, to a depth of a few inches, has been leached sufficiently to give a distinctly acid reaction when tested with Soiltex or La Motte Teskit solutions. In these same soils the subsurface layer is generally neutral or slightly alkaline in reaction, and the subsoil is distinctly alkaline.

Most of the soils have developed from alluvial deposits of different ages and of different degrees of coarseness or fineness. Much of this material, especially that in the alluvial fans, is derived from granite or granitic schists and has a coarse gritty texture, although the materials in small areas have been derived from basalt, andesite, and other volcanic rocks. The soils in the river valleys, or bottom lands, are developed largely from comparatively fine sediments of mixed lithologic composition. Differences in age, vegetation, and climatic environment seem to determine the most important soil differences. The soils developed from materials of different composition and texture, under similar climatic environment, tend to resemble one another with age. The character of the parent material probably has had considerable effect on the rate of development and on the texture of the resulting soil. The difference in lime content of the parent materials may explain the difference in liminess of the Tucson and Mohave soils described in this section of the report.

The soils may be broadly grouped into the more mature, or older, soils—those which have compact subsoils with more or less cementation by lime carbonate—and the recent, or younger, soils which are friable in both surface soil and subsoil, with but little modification or lime accumulation in the subsoil. The more mature soils are represented by a group of red soils including the Mohave, Tucson, and Palos Verdes soils, and a group of gray soils including the Pinal and Laveen soils. The recent and immature soils comprise a group of light-colored soils including the Gila, Cajon, and Anthony soils;

and a group of dark-colored soils including the Pima and Comoro soils, in addition to a few small bodies of soil mapped as a dark-colored phase of Gila loam.

The Mohave soils, where typically developed, are representative of the more mature red soils of the southern desert region, or Red Desert soils. The profile of Mohave sandy loam, described in the following paragraph, was examined on a gently undulating old terrace or alluvial fan near the northern end of the area, at an altitude of about 2,000 feet, where the annual rainfall probably averages about 10 inches.

The 4-inch surface soil is light pinkish-brown or light reddish-brown structureless and rather loose medium sandy loam or coarse sandy loam. It gives a slightly acid reaction. From a depth of 4 inches and extending to a depth of 20 inches, the material is compact red or dull-red sandy loam having a cloddy structure. This material shows no lime carbonate, but it reacts slightly alkaline by the La Motte test. From a depth of 20 inches to a depth of 40 inches is a layer of dull-red compact cloddy heavy sandy loam or clay loam, which is distinctly calcareous and contains a few white lime mottles. Below this and extending to a depth of 53 inches is compact nodular gray and pinkish-brown softly cemented material which grades into similar material that is slightly less gray and less nodular.

Typical Mohave loam and Mohave clay loam are similar in profile to Mohave sandy loam but are heavier in texture throughout.

Tucson loam is similar to Mohave loam and might be considered a calcareous phase of that soil, as it contains more calcium carbonate in both the surface soil and subsoil than Mohave loam. On this account the upper subsoil layer is more granular and friable, but the lower subsoil layer is harder and more firmly cemented. It has a more dull or gray color and less red. It somewhat resembles the Laveen soils of the group of gray soils. A sample of Tucson loam was taken on a smooth upland plain or very gently sloping alluvial fan, where the vegetation consists largely of a thin growth of small grass, together with scattered mesquite, creosotebush, and burroweed.

The surface soil, to a depth of 4 inches, is dull-brown or light reddish-brown coarse gritty loam. The material has little structure and forms soft easily crumbled clods. It is rather highly calcareous. From a depth of 4 to a depth of 19 inches is pinkish-brown or pale reddish-brown gritty heavy loam or clay loam, which shows a very fine netting or veining of white lime carbonate. The material in this layer is friable or slightly compacted and forms clods somewhat harder than those of the surface layer. At a depth of 19 inches and reaching to a depth of 30 inches, the material is rather compact cloddy gritty clay loam with a reddish-brown or dull-red color, mottled and streaked with white lime carbonate. Beneath this and extending to a depth of more than 6 feet is pinkish-gray or almost white very compact or softly cemented material.

This soil occurs under similar conditions of rainfall, elevation, and surface relief to those under which Mohave loam and Mohave sandy loam have developed, but for some reason it contains more lime in both surface soil and subsoil. Much of this soil is in proximity to the very calcareous Pinal soils, and possibly it has been derived in part from

outwash from the Pinal soils lying at higher elevations. It may, in places, be formed from an old limy subsoil which has been exposed by erosion. The surface soil has not yet been sufficiently leached to remove the large quantity of lime carbonate contained in the parent material.

The Palos Verdes soils are similar to the Mohave soils, but they have a more firmly cemented or indurated subsoil which has the character of a hardpan, but this material is not so hard as that in the Pinal soils. The material in the B_1 horizon is much harder than that in the Mohave soils, being cemented, apparently, largely by iron oxide. The B_2 horizon is a lime-cemented hardpan, and in many places a loose porous layer (the C_1 horizon) is present between depths of 3 and 6 feet below the surface.

The Laveen soils belong to the group of Gray, or Sierozem, soils. The surface soils and upper subsoil layers are light grayish-brown or pinkish-brown material of friable, granular, or soft cloddy structure. The lower subsoil layers are light gray, very compact, and softly cemented. In most places lime nodules are scattered over the surface and throughout the surface soil and subsoil. Following is a description of a profile of Laveen gravelly sandy loam.

0 to three-fourths inch, a rather loose surface concentration of gravel, coarse sand, and sandy loam, which is light grayish brown in color with a slightly pink tinge. The material is distinctly calcareous.

Three-fourths to 14 inches, light grayish-brown or pale pinkish-brown loam or heavy sandy loam, which is friable but firm and contains some gravel. The material is highly calcareous and contains faint nettings or veinings of gray lime carbonate.

14 to 26 inches, light reddish-brown friable gritty loam veined and mottled with gray lime carbonate and containing much gravel.

26 to 44 inches, mottled light-gray and pinkish-brown gritty loam having a rather compact softly cemented and nodular structure.

44 to 60 inches, rather firmly cemented light-gray material which breaks out in large chunks. It contains many gravel and cobbles.

60 to 72 inches, light-gray gravelly sand which is thoroughly impregnated with lime carbonate but is very slightly cemented.

The Pinal soils, which occupy rather large areas, differ from any of the soils previously described. The most important distinguishing characteristic of these soils is a light-gray firmly cemented lime hardpan, or caliche, which is commonly overlain to a depth of a few inches by coarse sandy light grayish-brown or pinkish-brown soil. The thickness of this soil layer ranges from a film to as much as 3 feet (11 inches where the sample was taken). The upper part of the hardpan is in general very hard, in some places platelike. It is 14 inches thick where the sample was taken. This layer is practically impervious to the passage of water and roots except where fractures occur. Beneath it and reaching a depth of 60 inches is light-gray more softly cemented material, and below a depth of 60 inches is still softer, less cemented, pinkish-brown coarse sandy loam.

Probably in most places the surface soil is derived from a comparatively recent surface deposit overlying an older formation represented by the hardpan and underlying layers. This is evidenced in a large number of exposures which show no gradation from surface soil to hardpan as is usual in such soils. It seems probable that the hardpan was formed, the former surface soil (if any surface

covering existed) removed by erosion, and a fresh layer of material deposited by wind, surface wash, and burrowing animals. Breazeale and Smith (*2*) give a number of interesting theories concerning the formation of caliche in this area. They state that caliche may be formed by the evaporation of lime-charged waters—either descending surface water or ascending ground water—and by the roots of plants, but that, in their opinion, the caliche on the mesa around Tucson was formed by evaporation of surface or flood water at the surface, or by precipitation in shallow ponds, or playas, "hastened by the presence of algae and other water plants." Doubtless several causes of formation may have operated at different times. It seems possible that lime-charged water, trickling over the surface of a subsoil exposed by erosion and already partly cemented by lime, deposited the thin platelike layers of very hard almost pure lime carbonate, as the water evaporated. It was the purity of the lime carbonate in these layers, which led Breazeale and Smith to conclude that it was formed on the surface rather than in the subsoil.

The Anthony soils are younger, less fully developed, and represent a very youthful stage in soil profile development. They are derived from the same gritty alluvial-fan materials, but no very definite soil horizons have developed. These soils are light brown or dull reddish brown, the red generally being somewhat more pronounced in the subsoil. The surface soil is commonly not calcareous, but the subsoil is distinctly limy and contains faint gray mottlings or fine netlike veinings of lime carbonate, but with no pronounced illuviated horizon, compaction, or cementation.

The Gila soils which, together with the Cajon soils, represent the light-colored unmodified soils recently developed from alluvium, are light brown, light grayish brown, or pinkish brown. They are generally deep, friable, variously and irregularly stratified, and calcareous throughout. The subsoils are very similar to the surface soils and in many places indistinguishable from them, though in most places a very slight accumulation of lime has taken place, taking the form of a very fine netlike veining of light-gray color. This may be seen in an undisturbed cut but is not apparent in many of the samples. In this area some of the heavier textured subsoil strata are dark gray like the corresponding layers of the Pima soils. Such material contains more organic matter than the lighter colored materials and is not conspicuous in the Gila soils in areas previously mapped. It is more common in the heavier textured types—silty clay loam and silt loam—than in the lighter textured types.

The Cajon soils are similar to the Gila soils, but they are coarser, looser, and more leachy. They occur on alluvial fans and on some of the coarser deposits in the valley. They may or may not be calcareous.

The Pima soils are representative of the dark-colored soils recently developed from alluvium. They are heavy-textured soils containing a comparatively large quantity of organic matter. They are distinctly calcareous throughout, with a slight accumulation of lime in the subsoil in the form of faint gray mottling or veining. They generally contain salts in easily detectable quantities, and in places the concentration is so strong as to injure or prevent plant growth.

Pima silty clay loam has a granular and fairly friable surface soil and a subsoil of cloddy structure, which breaks down rather readily into a granular mass. The subsoil is similar to the surface soil in color and structure but in many places is irregularly stratified with material of lighter texture and color. Pima clay is heavier, and its toughness is caused by its heavy texture. Whether the dark color of the Pima soils is due to organic matter eroded from more elevated dark-colored soils and already present in the soil material when deposited, or whether it has accumulated in the soil from the growth and decay of vegetation after deposition of the material, is not definitely known, but probably one explanation may apply in some places and the other in other places. In some places the dark-colored deposit is obviously the result of recent sedimentation, but in other places it seems that a high water table once existed and that a heavy vegetation caused the formation of organic matter in the soil. Below San Xavier Mission a dense growth of mesquite and scattered hackberry trees covers an area of several square miles, and under them in places a litter of leaves and twigs an inch or more thick is present. Bryan (*3*) states that erosion, within historic times, has lowered the course of Santa Cruz River. If this be true, the ground water once stood at a higher level and conditions were favorable for a heavy vegetal growth on these soils.

The soils of the Santa Rita Experimental Range present a much wider range of soil characteristics, owing, directly or indirectly, to differences in elevation and proximity to the mountains. With greater elevation and closer proximity to the mountains rainfall increases, ranging from 9.48 inches at an elevation of 2,900 feet at Northeast station, to 18.92 inches at Parker station at an elevation of 4,250 feet. Also, at the higher elevations there is a corresponding decrease in temperature, the grass growth is much more plentiful, and the soils are darker, have a higher content of organic matter, and are more deeply leached of lime carbonate and other soluble compounds. These soils might be considered a link between the slightly leached Gray or Red Desert soils and the leached soils of more humid climates. One soil—Tumacacori coarse sandy loam—resembles a Prairie soil, whereas others, especially the White House soils, have a soil development somewhat similar to that of the Red soil of southeastern United States, but they are not leached to nearly so great a degree.

The typical mature soil development of soils in the upper part of the area is shown in a study made of White House gravelly sandy loam on a high, smooth, moderately sloping alluvial fan near White House station at an elevation of about 3,900 feet. This is, apparently, a very old undisturbed surface which lies about 50 feet above a large drainage channel about one-fourth mile to the east. A description of the profile follows:

A_1. 0 to 1½ inches, a loose layer of pale-red gravelly sandy loam, which has a slightly acid reaction (pH 6.5).

A_2. 1½ to 10 inches, dark reddish-brown or dark-brown friable granular sandy loam or loam, which apparently contains considerable organic matter. This layer is slightly acid.

B_1. 10 to 28 inches, intensely dark red or maroon clay containing much gravel and stone. The material has a dense cloddy or irregular blocky structure,

with vertical cracks or cleavage planes, through which dark organic matter and roots have penetrated. The material in this horizon, like that in those above, is slightly acid.

B_2. 28 to 42 inches, brownish-red tough clay containing a large quantity of disintegrating rock. The material has a neutral reaction.

B_3. 42 to 60 inches, a mass of disintegrating boulders (rhyolite, trachyte, granite, syenite, diorite, and other rocks), through which have penetrated tongues of tough red clay. The material in this horizon gives a slightly alkaline reaction by the La Motte test, but it does not effervesce when treated with hydrochloric acid. At a depth of 60 inches there is a mass of boulders which cannot be dug through.

A deeper study was made in some high cut banks in a similar soil lying at an elevation about 200 feet lower, on the same fan. Here the subsoil is calcareous and somewhat grayer (pinkish brown or pinkish gray) at a depth ranging from 4 to 6 feet below the surface. Cementation occurs in only a few places.

The extreme development of the red clay subsoil has doubtless taken place during a long period, which has resulted in the disintegration and decomposition of the soil material, the deep leaching of lime carbonate and other soluble salts, and a downward movement, partly mechanical and partly in colloidal solution or suspension, of iron and aluminum oxides. The hot climate has undoubtedly been conducive to intense oxidation. This has caused the formation of a large amount of iron oxide, which imparts the red color to the surface soil and subsoil. Oxidation also destroys much of the organic matter produced by grass, especially on the immediate surface, which is covered by a thin layer of pale-red material comparatively poor in organic matter.

On the lower and drier alluvial-fan slopes of the experimental range, on the old, undisturbed tablelike areas lying between deep drainageways, and in other smooth, very gently sloping areas on the lower fans, the Continental soils have developed. They are very similar to the White House soils, but have a somewhat lighter colored surface soil, containing less organic matter, and are not so deeply leached. They have the same tough, heavy red upper subsoil layer which in many places has a somewhat columnar or prismatic structure, but below a depth ranging from 12 to 24 inches (20 inches where the sample was taken) the subsoil becomes distinctly calcareous, and at a depth ranging from 2 to 3 feet a layer of gray material, more or less cemented by lime, is present, in some places forming a hardpan, or caliche, having the appearance of a conglomerate.

The Tubac soils, which occupy small areas on the lower and drier margins of the alluvial fans and extend into the upland terraces and fans of the valley part of the area, represent the most extreme profile development of the soils in the area. These soils apparently are transitional between the partly leached and darker colored soils of the more elevated fan slopes and the true Desert soils of the lower lying drier and hotter valley.

The Tubac profile (fig. 2) accords with the following description of Tubac sandy loam as observed on a smooth, gently sloping alluvial fan, perhaps 200 feet above the valley of Santa Cruz River, at an elevation of nearly 3,000 feet.

The surface is covered with a thin veneer (one-half inch thick) of pale-red or light reddish-brown loose sand which apparently is derived largely from granite. The particles are angular—most of them quartz—with a thin coating of red material, probably iron oxide. Beneath this surface veneer, and continuing to a depth of about 7 inches, is dull reddish-brown firm but friable sandy loam having little structure but breaking up in soft easily crumbled clods. The material in neither of these two layers effervesces with hydrochloric acid, and tests with Soiltex and La Motte Teskit solutions indicate a distinctly acid reaction. Abruptly underlying the surface soil and contrasting with it sharply in color, texture, and structure is a layer, between depths of 7 and 16 inches, of dark-red tough heavy clay

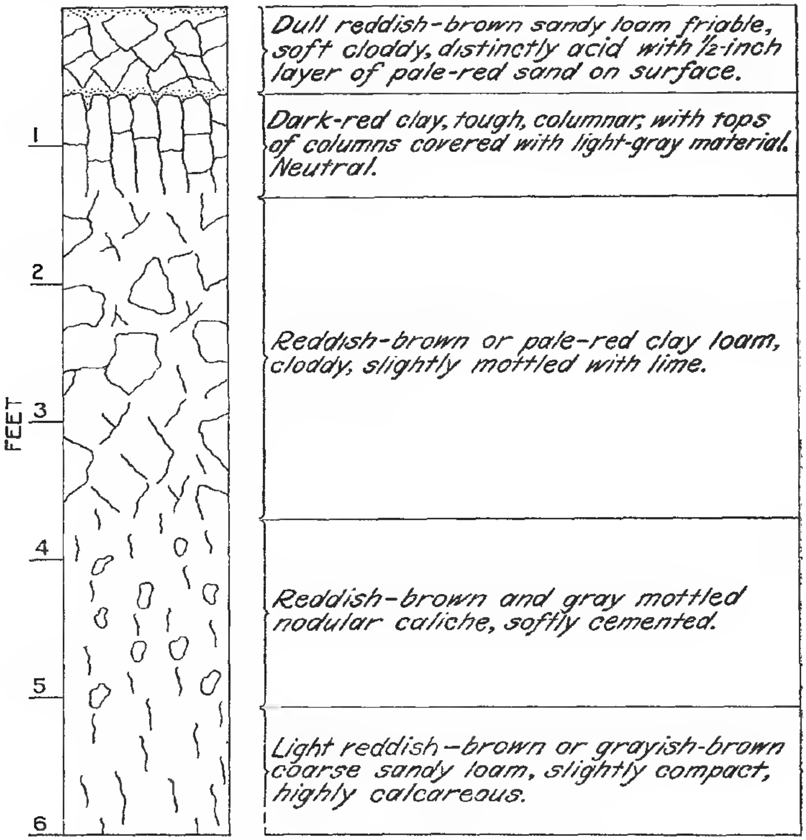

FIGURE 2.—Diagram of a profile of Tubac sandy loam.

loam or clay, with a distinct columnar or coarse prismatic structure. The prisms range from 2 to 5 inches in diameter. They are hard, resist crumbling or breaking, and are very dense. Capping each prism is a thin layer (one-half inch thick) of light-gray siliceous material which follows the cracks or cleavage planes downward for several inches. This layer contains no lime carbonate and has a neutral or slightly alkaline reaction.

From a depth of 16 inches and extending to a depth of 44 inches is compact cloddy reddish-brown or pale-red clay loam slightly mottled with gray lime carbonate and flecked with dark-gray or black material, probably organic matter. Between depths of 44 and 60 inches is mottled light reddish-brown and gray material which is compact and softly cemented by lime carbonate. The structure is somewhat nodular. From a depth of 60 inches to a depth of more than 72 inches is light reddish-brown or grayish-brown coarse gritty loam or coarse sandy loam, which is highly calcareous and somewhat compact but is much softer than the material in the layers above.

Tubac gravelly clay loam and Tubac clay loam have profiles similar to that of Tubac sandy loam, but they do not show such marked textural differences between the surface soil and subsoil. The differences in color and structure are almost equally as marked.

The Tubac soils, as may be inferred from the description, have a profile resembling the solodized-Solonetz. They differ from the Solonetz soils described by Glinka (7) in that they are red in both surface soils and subsoils, and they have distinctly acid surface soils, with neutral or very slightly alkaline upper subsoil layers, or B_1 horizons. The lower horizons of the subsoils, however, are alkaline in reaction, and 2 out of 3 samples showed rather large percentages of soluble salts when tested with the electrolytic bridge. A sample of Tubac sandy loam showed slightly more than 0.1 percent in the material between depths of 16 and 72 inches; and a sample of Tubac clay loam showed about the same amount between depths of 13 and 36 inches, and almost 0.3 percent between depths of 36 and 72 inches. Each of these two subsoils gave a faint test for sodium carbonate when tested with phenolphthalein.

These soils have formed under a climate where considerable amounts of rain fall in the hot summer season and other considerable amounts in the cool winter season. The summer rains occasionally penetrate to a depth ranging from 1 to more than 2 feet. Such a moist condition in the heat of summer would cause great chemical activity, and it seems likely that laterization or kaolinization may take place to a great extent in this soil in summer. Basing their opinion on the presence of wide-spread remains of Indian settlements in now arid districts,[8] archaeologists suggest the possibility of a former higher rainfall existing in the area. The varied arboreal vegetation also suggests that it may be remnants of a more luxuriant vegetation holding over from a former time when rainfall was higher. If this be true, these soils were formed under conditions somewhat similar to those in more humid regions, and they resemble such soils in some of their characteristics. A mechanical transference or filtering down of the finer materials from the surface to the upper part of the subsoil, together with the release and downward movement of colloidal iron oxides and aluminum silicates, has doubtless taken place.

The Sonoita soils may be considered as a young, or partly developed, stage of the Continental or Tubac soils, as they have the same succession of horizons, but not so well developed, clear cut, and distinct. The upper subsoil horizon is not so intensely red, not so heavy in texture, and lacks the massive cloddy structure of the Con-

[8] Byron Cummings, archaeologist of the University of Arizona, made this statement to the writers.

tinental soils, and the columnar, or prismatic, structure of the Tubac soils. The upper subsoil horizon is dull-red or brownish-red gritty loam or clay loam, which is hard and cloddy when dry. Below a depth of about 45 inches, the subsoil is faintly mottled or veined with lime.

The Pinal soils of the experimental range are thin highly calcareous gray and dark-colored soils overlying a lime-carbonate hardpan. Comparatively little organic matter has accumulated in the surface soil of the typical Pinal soils, whereas a rather large amount has accumulated in the surface soil of the dark-colored phase (2.3 percent in the sample analyzed), and a dark soil color has resulted.

A variation occurs in the red phase of Pinal gravelly sandy loam, where the surface soil consists of a few inches of friable calcareous red gritty loam over the lime hardpan. Apparently this soil has lain undisturbed long enough to become highly oxidized, but it has insufficient depth or too high a lime content to develop tough subsoil horizons like those of the White House and Tubac soils.

Two distinct types of soils developed in place on stony buttes or foothills occur in the area—Coronado stony coarse sandy loam and Coronado stony loam. Coronado stony coarse sandy loam is developed from materials weathered from granite or syenite bedrock, which disintegrates and produces a coarse gritty soil material. The surface soil, where normally developed, is dark reddish-brown coarse sandy loam containing a rather large quantity of organic matter; the subsoil, where the material is of sufficient depth, is red gritty loam or clay loam, and the upper part of the granite is soft, crumbly, and permeated with a red stain. Coronado stony loam is very similar to the stony coarse sandy loam, but, being derived from weathered rhyolite, trachyte, and similar fine-grained rocks, is finer in texture. It is also somewhat darker.

Associated with the older and more maturely developed soils of the experimental range are representatives of two series of rather dark colored soils of comparatively high organic matter content, of recent accumulation, and with an undeveloped or very youthful profile. These are the Comoro and the Tumacacori soils.

The Comoro soils were recognized and mapped in the Nogales area, which joins the Tucson area on the south, where they occur in the Santa Cruz River Valley and extend for a short distance into the Tucson area. They are developed from recent accumulations of alluvium having its source in higher lying and more humid areas of darker colored soils.

The Comoro soils are very similar to the Cajon soils, but they are slightly loamier in texture and have brown or dark-brown surface soils containing much organic matter. The surface soils and subsoils in many places have a distinct red tinge, indicating that some oxidation has taken place.

The Tumacacori soils, which occur also in the Nogales area, have a comparatively high content of organic matter and a dark-brown, dark grayish-brown, or almost black color, which extends to a depth of as much as 4 feet. The subsoils are loose, open, and in general free from accumulations of lime carbonate to a depth of as much as 8 feet below the surface. According to the La Motte test, the ½-inch surface layer is slightly acid, but the material below that depth and continuing to a depth of 8 feet is neutral. These may be " skeleton

soils" which, on account of their loose, open structure and coarse texture, have been leached so deeply that formation of horizons has been impossible.

SUMMARY

The Tucson area lies in Pima County, Ariz., and comprises the valleys of Santa Cruz River, Rillito Creek, and tributary streams, with narrow bordering strips of upland mesas and alluvial fans. The total area is 432 square miles. The elevation of the valley part of the area ranges from 1,800 to 3,000 feet. The area surveyed includes an extension on the southeast which covers the Santa Rita Experimental Range under administration of the United States Forest Service. This range comprises about 53,000 acres of land at the foot of the Santa Rita Mountains south of Tucson. The purpose of this inclusion is to study the soils as related to range problems, among which are the reestablishment of grasses following overgrazing, and the carrying capacity of the range. The elevation within the reserve ranges from less than 2,900 feet to about 5,200 feet, and Mount Wrightson, a short distance to the southeast, rises to a height of 9,432 feet. The surface relief is characterized by the long sloping alluvial fans descending from the mountains, and a few small isolated buttes and small areas of the foothills which are included in the area surveyed.

The climate here, as in other parts of the arid Southwest, is characterized by low annual rainfall, a dry atmosphere, long hot summers, and short mild winters. On account of the comparatively higher elevation and proximity to the mountains of the experimental range part of the area, both heat and aridity are modified here, and at the upper edge of the range the climate approaches that of cooler and more humid regions. The rainfall occurs at two distinct seasons—the summer season, from June to September, and the winter season, from November to February.

Native vegetation in the valley part of the area is dominantly creosotebush, with bur-sage, desert sage, mesquite, paloverde, ironwood, ocotillo, and cacti of several species. The vegetation in the experimental range consists mainly of desert shrubs in the lower or semidesert country and largely of grasses in the higher mesa and foothill areas. Mesquite and burroweed are the most abundant brushy plants, and the grasses include Rothrock grama, black grama, slender gramas, side-oats grama, *Muhlenbergia porterii*, *Aristida californica*, *A. arizonica*, tanglehead, curly mesquite, cotton grass, and *Triodia mutica*.

Tucson is the county seat and the only incorporated city. It is an important health and winter-tourist resort, railroad division and junction point, the seat of the University of Arizona, and a supply point for the surrounding grazing, agricultural, and mining districts.

Agricultural development is not extensive, and the present trend in cultivated acreage is downward, owing to the small supply and high cost of water for irrigation and the general low level of prices for agricultural products. The principal crops are alfalfa, cotton, hegari (a grain sorghum), barley (for hay, pasture, and grain), and pasture grasses. Minor crops are wheat, potatoes, truck crops, peaches, apricots, figs, and grapes. Citrus-fruit plantings have been

made, but the trees are not yet (1931) in bearing. Much of the land included in the agricultural census data is grazing land either within or outside the Tucson area.

The chief agricultural soils are those of the Gila and Pima series. They are, for the most part, deep friable soils having good water-holding capacity and high productivity. Gila fine sand is loose and leachy and is not well suited to irrigation farming, and the same is true of Cajon sand. The Anthony and Comoro soils are outside the cultivated area but if supplied with irrigation water would doubtless be productive. The soils of the Tucson, Mohave, and Laveen series have softly cemented limy subsoils which soften and are fairly pervious when moist. Small bodies of Tucson loam, Mohave sandy loam, Mohave clay loam, and Laveen sandy loam are under cultivation and, although naturally somewhat less productive than the Gila and Pima soils, produce fairly good yields of the crops commonly grown.

The Pinal and Palos Verdes soils have firmly cemented lime hardpan, or caliche, layers. Trees may be grown on these soils by digging or blasting holes through the hardpan layer. A small planting of citrus fruits has been made on the Palos Verdes soil.

The Tubac soils have tough red upper subsoil layers and compact gray limy lower subsoil layers. They are not under cultivation, as they occur on high land without a water supply.

The soils of the Santa Rita Experimental Range, included in the Tucson area, have developed under a much wider range of environmental conditions and represent a wider range in color, organic-matter content, and profile development. Some of them, mainly those of the lower lying and more arid alluvial fans, occur also in the valley part of the area, and others are developed under the less severe desert conditions or more abundant rainfall of the higher and steeper alluvial-fan slopes and foothills.

The soils in the range include both dark- and light-colored soils of recently accumulated alluvium, which have little or no profile development; old dark-brown, red, or reddish-brown soils having tough red subsoils of blocky or prismatic structure; and old gray soils of high lime content, having more or less firmly cemented lime-carbonate, or caliche, subsoils.

The soils of the first group are represented by the dark-brown Comoro and Tumacacori soils and the light-colored Cajon soils which are of much lower organic-matter content. The old and more maturely developed and leached soils are represented by the red or reddish-brown Continental and Tubac soils, with tough heavy-textured subsoils, and by the darker colored White House soils which have a higher content of organic matter.

Associated with these are the Coronado soils which are shallow soils developed on stony foothills and buttes, and the Sonoita and the Mohave soils, although the latter are less maturely developed in profile and are intermediate between the soils of the first and those of the second group. The old gray, highly calcareous soils are represented by the Pinal and the Laveen soils, which are also extensively developed in the lower valley part of the area surveyed. The Tucson and the Anthony soils, which occur more extensively in the valley, are also represented in the more arid parts of the Santa Rita Range.

In the Tucson area, the role of soils in determining the plant distribution is important, but perhaps second in importance to rainfall. Biotic factors, such as grazing by cattle, the activities of rodents, and plant competition and succession, are also very important.

In the higher parts of the area, where the rainfall is greater and the temperature lower, grasses grow nearly everywhere, regardless of the character of the soil, but in the lower drier parts they grow well only on the comparatively deep, loose sandy loams or comparatively small spots having a loose surface covering of sand, gravel, leaves, litter, or material thrown up by burrowing rodents. The chemical character of the soil seems to have less influence on plant distribution than the physical characteristics, although there are some exceptions. The calcareous soils seem to favor the growth of creosotebush and *Triodia mutica*, and it is also probable that grasses will make a taller and more vigorous growth on the darker, more highly organic soils. Curly mesquite seems to prefer red surface soils which are closely underlain by heavy red subsoils or bedrock. The same is true of *Calliandra*. Burroweed also grows largely on the red soils but is not confined to them.

Entirely different types of vegetation or plant associations grow in some places on apparently identical soils. In many places, this probably is owing to an invasion of brushy types of vegetation, notably burroweed and mesquite, onto grasslands, possibly following the killing of the grass by overgrazing.

Comoro coarse sandy loam is the most extensive soil in the experimental range and is an important grass-producing soil at the lower elevations. Comoro sandy loam and Comoro loam are similar but finer textured soils. Tumacacori coarse sandy loam is a deep, dark-colored soil rich in organic matter. It is extensive and is one of the best grass soils in the range. Tumacacori gravelly loam is of small extent, which produces mainly a thick growth of mesquite. The Cajon soils are of little extent or importance. The White House and the Continental soils are for the most part good grass soils, but they are subject to damage by erosion, and in shallow spots the stand of grasses is absent or thin. White House gravelly sandy loam and its stony phase and White House coarse sandy loam and its stony phases and deep phase are in most places good soils for grass. Continental sandy loam is a somewhat inferior soil for grass, and Continental gravelly loam and White House gravelly loam do not produce much grass. The Tubac soils produce very little grass but considerable brush. Sonoita sandy loam produces good grass in some places, but in other places the vegetation is mostly burroweed and mesquite. The Anthony, Mohave, and Tucson soils are of little extent and importance, producing mostly brush, although the Anthony soils produce good grass in places. The Laveen soils at the lower elevations produce little vegetation besides creosotebush, but at the higher elevations there is a rather thin stand of grasses, paloverde, mesquite, and yucca. There is little grass except low tridens on the Pinal soils, but the gravelly slopes of this soil support a scant growth of other perennial grasses and much mesquite, paloverde, and catclaw.

Apparently erosion is not severe in the greater part of the experimental range, although it is progressing rapidly in rather small areas. The maintenance of a grass cover is important in minimizing its effects.

Rough broken and stony land includes areas which are too rough, steep, or stony for cultivation, and river wash consists of the loose, sandy, or gravelly material in the channels of intermittent streams.

Irrigation is necessary for the production of crops in this area, and the water supply is the limiting factor in agricultural development. Most of the irrigation water must be pumped from wells. The greater part of the area is well drained, and an injurious accumulation of "alkali" or salts is confined to a few restricted localities such as the comparatively small areas in the Santa Cruz River Valley southwest and northwest of Tuscon and along Rillito Creek.

The soils of this area need organic matter (nitrogen and humus) in order to increase and maintain productivity. Applications of superphosphate result in more vigorous growth and earlier maturity of a variety of crops. Crop rotation, including the growing of alfalfa, sweetclover, or some other legume, is essential to continued satisfactory crop production.

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SOIL MAP
TUCSON AREA
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Soils surveyed by F. O. Youngs, in charge,
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and E. N. Poulson.

Scale 1 inch = 1 mile

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